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tentative

guide to  
geologic  
investigations  
of dam sites

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## PREFACE

This draft of "Guide to Geologic Investigations of Dam Sites" is a preliminary draft intended to be used solely for review purposes and as a training tool in connection with Soil Conservation Service training schools on the Unified Soil Classification System. Only a limited number of copies have been reproduced for this purpose. It was originally intended to issue the Guide as Technical Release No. 7 and it is referred to as such in Engineering Memorandum No. 33. Subsequent determination removed it from this series and final publication will be in its present format. The first draft of the Guide was completed in September 1958, and copies distributed to Engineering and Watershed Planning Unit personnel for review and comment. The suggestions received from the units were reviewed at a meeting of Engineering and Watershed Planning Unit and Central Technical Unit engineering geologists held at Washington, D. C. during the week of December 1-5, 1958. Also participating in this meeting were the Director of the Engineering Division, the Staff Geologist, the Chief of the Design and Construction Branch and the Head of the Soil Mechanics Laboratory. This Guide incorporates the suggestions agreed upon at this meeting.

This Guide is considered to be tentative pending final review of a report and recommendations to be submitted to the Service by a firm of consulting engineers employed to conduct a study of Service procedures for site investigations, soil mechanics, and design. A final review of the Guide will be made during the week of July 13-17, 1959, after which a final copy will be reproduced for National distribution to Service personnel. Further suggestions and comments are solicited. These should be directed to the Staff Geologist, Engineering Division, Washington, D. C., to be received not later than July 10, 1959, for consideration.

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## CHAPTER 1. INTRODUCTION

### Purpose and Scope

The choice of design and construction methods for a particular dam is contingent upon the characteristics of materials of which and on which the structure is to be built. Knowledge of these materials, sufficient in scope and quality, to satisfy design and construction requirements is necessary for each site if consistent development of economically sound and practical structures is to be achieved. Such knowledge is acquired through practical experience in a particular area, by thorough geologic examination of sites, by accurate foundation and borrow exploration, and precise soil mechanics laboratory tests.

This guide presents basic information related to geologic investigations of dam sites for use of Soil Conservation Service geologists, engineers, and other technicians. The purpose of the guide is to present, in brief and usable form, information on equipment, tools, exploration and sampling techniques and criteria for conducting adequate site investigations. The scope is necessarily limited to phases of site investigations which pertain directly to the programs of the Soil Conservation Service. The material is compiled to assist technicians in planning site investigations, carrying out field investigations and preparing reports within the framework of established Service standards. The guide also will serve as a useful tool for training purposes and to promote establishment of uniform standards and procedures.

This guide is not intended to be a complete technical treatise on the subject of site investigations. Nor is it intended to establish a stereotyped pattern for site investigations. Each structure site has its own particular characteristics. The geologist must establish a pattern of investigations and application of exploration and sampling methods contingent upon the site to obtain the information needed for design and construction. This requires sound judgment and a knowledge of requirements for design and construction as well as a knowledge of exploration and sampling techniques. The geologist conducting site investigations must become thoroughly familiar with basic principles and techniques in the fields of engineering geology, soil mechanics, design, etc., to achieve technical competence. He must work closely with the project and design engineers on each site in order to determine the requirements for that particular site and to establish his investigational procedures accordingly.

### Use of Earth Materials

The use of earth materials is stressed since these materials have three aspects of major importance. First, the materials are usually present in abundance in the immediate area of the structure; second, the materials have properties which compare favorably with the engineering properties of man-made materials and; third, the natural supply allows a greater economy than man-made, imported materials.

Embankments.

The use of natural materials in embankments is related to their inherent capacity to be remolded with, in some types, an accompanying modification in their engineering properties. The reshaped, remolded surfaces are also able to support a protective cover of vegetation. Earth embankments may be homogeneous or zoned with the materials pre-selected and remolded to form an essentially water-impervious barrier as well as a structurally strong unit.

Riprap may be placed above and on the sides of the embankment in such a manner as to afford the maximum protection from the impact of water, weather, and other physical and chemical actions.

Foundations.

The use of earth materials in structural foundations presupposes that the material must and will support, without danger of failure, rupture, or displacement, the load of materials to be superimposed upon it.

The types of foundations range from bedrock to unconsolidated sediments and, as the types vary, so must the method and intensity of the determination of fitness vary.

Spillways.

The spillway functions as an automatic control of the waters impounded by a structure. By virtue of its stability and resistance to geologic and hydraulic destruction, the spillway insures the life of the entire structure. Open spillways are usually subjected to the most severe conditions of geologic erosion as a result of their purpose and function. When they are to be constructed of or in erodible materials, great care should be given to the identification and classification of the materials.

### Engineering Properties of Soil Materials

General.

The term "soil materials" is here defined as the unconsolidated products of erosion and decomposition of rocks and may include organic material. "Soil material" or "soil" consists of a heterogeneous accumulation of mineral grains, including most every type of uncemented or partially cemented inorganic and organic material to be found on the earth's surface.

Following is a brief discussion of some of the more important engineering properties of soil materials with which the geologist must be familiar in order to achieve technical competence. For further details he is referred to standard textbooks on soil mechanics and Section 7. - Soil Mechanics, of the National Engineering Handbook. For details of application of engineering properties to the design of Service structures he is referred specifically to Section 9. - Earth Embankments.

Gradation.

Gradation is the amount and distribution of the various grain sizes in a given soil. The grain-size distribution is an important indication of the physical properties of a predominantly coarse-grained soil but gradation is not as significant for essentially fine-grained soils. Typical

descriptions of gradations in soils are: (1) Well-graded; which indicates a good representation of all particle sizes from largest to smallest and (2) poorly graded; which indicates most particles are about the same size or that there is an absence of some intermediate sizes.

#### Consistency.

Consistency refers primarily to the moisture content of a soil, but also to its plastic characteristics. It is a physical property which is most conspicuous in fine-grained soils. As a very wet fine-grained soil dries, it goes through various stages of consistency, from a liquid to a solid state. In the very wet condition the mass will act as a liquid and this is called the liquid state. With drying the mass loses its ability to flow, becomes stiffer, can be easily molded, and retains its shape. This is the plastic state. With still further drying, the volume shrinks and the material becomes hard. When the soil mass has decreased in volume to the point where further loss of moisture will not cause shrinkage it has reached the shrinkage limit and is in the solid state.

The liquid limit is that moisture content where the soil mass will act as a very weak plastic and any additional water will cause the soil mass to act as a viscous liquid.

The plastic limit is that moisture content above which the material can be deformed without rupture.

These transition points between states of consistency are known as Atterberg Limits.

The plasticity index is the difference between the liquid and plastic limits and represents the range of moisture through which a soil will remain plastic. Clays have high to moderate plasticity indices. Silts have low plasticity indices. The plasticity index is influenced by the fineness, shape, and mineral composition of the fine-grained particles.

#### Density.

The density or unit weight of a soil is defined as the weight per unit volume. The dry density is the weight of the mass excluding the weight of the contained water. The wet density includes the weight of the contained water.

#### Moisture Content.

The moisture content is the ratio of the weight of water contained in the soil to that of the soil solids. This value is expressed as a percent.

Density, or unit weight, and moisture values are highly significant in embankment construction. A certain density may be specified to which the soil is to be compacted, and the moisture content at the time of compaction is very important for many soils.

#### Penetration Resistance.

The penetration resistance is the resistance of a soil to the penetration of a small cylindrical needle, rod or tube. The penetration

resistance is a measure of the firmness of the soil and may be expressed in pounds per square inch or number of blows per foot of penetration. The factors influencing penetration resistance are gradation, plastic characteristics of the soil, degree of compaction, moisture content, and density.

#### Permeability.

The permeability of a soil is its capacity to transmit fluids under pressure. It may vary in different directions. The water flows through the voids between the soil grains. Therefore, the larger the size of the pores and their interconnections the greater the flow of water. It may be seen that coarse-grained soils are more permeable than fine-grained soils. A well-graded soil, having a good distribution of particle size from large to very fine, is relatively impervious because the finer grains fill the space between the larger particles.

#### Coefficient of Permeability.

The coefficient of permeability of a given soil, usually expressed in Meinzer's units, is the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot, under a hydraulic gradient of 100 percent and at 60° F.

#### Consolidation.

Consolidation refers to the volume change of a soil under load. Normally, fine-grained soils consolidate more than coarse-grained soils and poorly-graded soils consolidate more than well-graded soils. Density, plasticity, porosity, permeability, and organic content are important factors in determining the degree of consolidation.

#### Pore Pressure.

Pore pressure is the hydrostatic pressure developed in the pores of a soil. It has a large influence on the stability of a soil and on the rate of consolidation of the soil. The pore pressure produced is dependent upon the volume change of the soil mass, upon the compressibility of the water and air mixture in the void spaces and upon the permeability of the soil.

#### Shearing Strength.

Shearing strength represents the ability of a soil to withstand loading without excessive lateral deformation and is an important property in the determination of stability of foundation and embankment materials. If the vertical pressure exceeds the lateral support plus the shearing resistance of the soil, excessive deformation occurs.

## CHAPTER 2. DESCRIPTION OF MATERIALS

### General.

The adequacy of a geologic investigation of a structure site depends on accuracy of the descriptions and classification of materials at the site and proper interpretation in respect to engineering requirements. Materials at a particular site are to be described and classified according to their geologic and physical properties and also according to their engineering or behavior properties. The former are necessary to establish the stratigraphy and correlation of the site and the latter to develop the design of the structure and construction methods to fit a particular site condition.

Two systems of describing materials are, therefore, employed in Service work, geologic, and the Unified Soil Classification System. The geologic system is based on the geologic and physical properties of materials. The Unified System is based on a combination of physical and behavior properties. To some extent the two systems overlap and descriptions developed for geologic interpretations are also used for engineering interpretations. Thus the descriptions of coarse-grained unconsolidated materials in both systems are compatible. In other instances descriptions of features in the geologic system such as key minerals and fossils needed to establish correlation and continuity of strata have no counterpart in engineering classification and are of little concern in respect to engineering properties. Conversely, the use of engineering properties to define geologic factors has not been fully explored, but it appears that in certain materials the engineering properties provide a more useful basis of description than the physical or mechanical properties. Because of the fine-grained nature of clays, for example, classification on the basis of field examination is restricted. However, field classification on the basis of dilatancy, consistency, tenacity, plasticity, etc., provides a more significant classification than geologic factors alone. The geologist must use both systems in classifying materials and classification based on engineering properties should be included in the physical descriptions as additional information that is useful in establishing stratigraphy and correlation.

Procedures for describing materials on the basis of engineering properties for such materials as indurated rock have not been established so that it becomes necessary to rely on the physical descriptions of these materials for interpretation.

Both of these systems are discussed in this chapter.

Not only do the classification systems themselves vary in respect to the objectives of each system, but also the terminology used by engineers and geologists is often different. Engineering geology is a special branch of geology. A successful engineering geologist must have a substantial and intimate knowledge of engineering design and construction methods. He must understand the terminology used by engineers and he must be able to translate the common terms used by the geologist into common terms readily understood by engineers. Despite differences in viewpoint, it must be remembered that geologic investigations of dam

sites in Service work are made to obtain information for engineering purposes and, to be fully effective, must accomplish this purpose. The results must be in such form as to be fully understood by engineers. Therefore, this guide departs from the use of standard terms normally found in geologic texts to terms more readily acceptable to engineers. The following is a list of some of the more important commonly adopted engineering terms and their meanings for use in this guide to describe materials:

Rock.--Compact, semi-hard to hard, semi-indurated to indurated, consolidated mass of natural materials composed of a single mineral or combination of minerals.

Soils.--Unconsolidated, unindurated, or slightly indurated, loosely compacted products of disintegration and decomposition.

Grain.--A soil particle.

Gradation.--Relative size distribution of particles.

Well graded.--No sizes lacking or no excess of any size range - poorly sorted.

Poorly graded.--Sizes lacking or excess of certain size ranges - may be well sorted.

### Geologic Descriptions

#### Particle Characteristics.

Particle characteristics, including size, shape, mineral composition, etc., are important considerations in establishing the origin of materials and geologic processes involved, and for determining the stratigraphy of the site. Lithologic similarity is one of the bases for determining the equivalency in age needed to establish correlation and continuity of strata. Particle characteristics also are important considerations in establishing the engineering properties and behavior characteristics of materials. The following briefly outlines some of the properties of particles and methods of classification for dam-site investigations.

Size.--The important classifications according to size are: boulders, cobbles, gravel, sand, silt, and clay. The Unified Classification System will be used by the engineering geologists in Service work. The size of the particles is usually stated in terms of the metric system. Numerous grade scales, such as the Wentworth scale, have been developed to establish the limits of size of each of these classifications. Normally the grade scales consist of rather minor differences in dimensions of the class boundaries. The following table lists the Unified and Wentworth systems for comparison:

Table 2-1 Grade Scales

Class	Unified Classification Grading		Wentworth Grading
Boulders	Over 12 in.	Over 305.8 mm	Over 256 mm
Large cobbles	6-12 in.	152.4 - 305.8 mm :	64 - 256 mm
Small cobbles	3-6 in.	76.2 - 152.4 mm :	
Coarse gravel <sup>3/</sup>	3/4-3 in.	19.05 - 76.2 mm :	2 - 64 mm
Fine gravel <sup>3/</sup>	No. 4 sieve <sup>1/</sup> - 3/4 in.	4.76 - 19.05 mm :	
Coarse sand	No. 10 - No. 4 sieves	2 - 4.76 mm	1/2 - 2 mm
Medium sand	No. 40 - No. 10 sieves	0.42 - 2 mm	1/4 - 1/2 mm
Fine sand	No. 200 - No. 40 sieves	0.074 - 0.42 mm	1/16 - 1/4 mm
Silt	<u>2/</u>	————	1/256 - 1/16 mm
Clay	<u>2/</u>	————	Under 1/256 mm

1/ Sieve sizes apply to U. S. Standard

2/ Particles smaller than No. 200 sieve identified by behavior

3/ Called granules, 2-4 mm; and pebbles, 4-64 mm by Wentworth

Shape.--Geologists quantitatively express the degree of roundness of particles on the basis of the average radius of the corners divided by the radius of the maximum inscribed circle. Although particle shapes can be expressed numerically by this method, such a degree of accuracy is not required for geologic investigation of dam sites. Visual estimation is sufficient for classification of equidimensional particles. The following comparison chart of degrees of roundness and angularity will serve as a guide to visual estimation and classification of roundness.

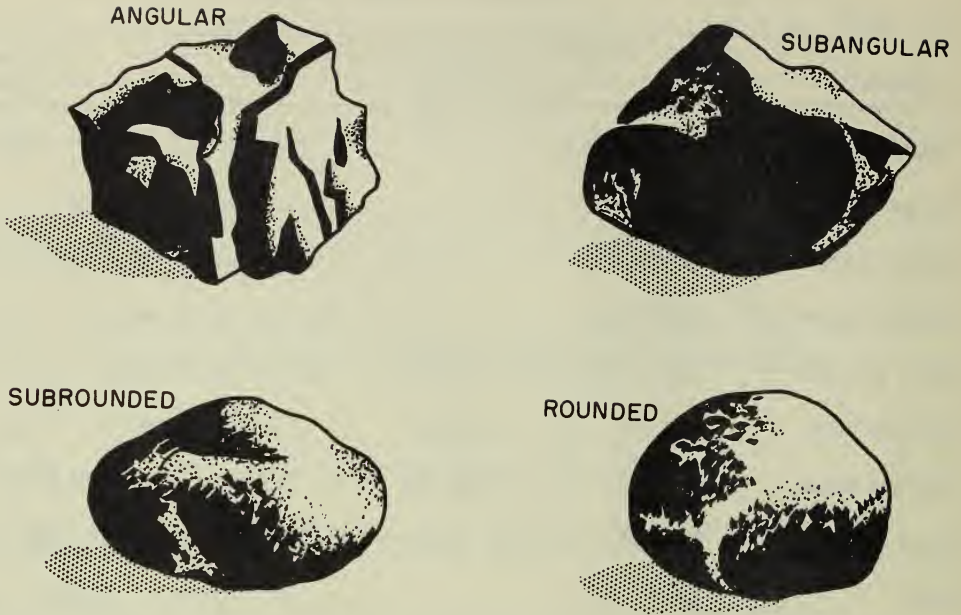


Figure 2-1 Shapes of Particles

The above classification is adopted primarily to equidimensional particles of materials coarser than silt particles.

Normally it is not adequate for expression of non-equidimensional constituents either in coarse or fine-grained fractions of materials. Where flaky minerals are present these should be described on the basis of the mineral name instead of the shape, viz., biotite, muscovite, chlorite, etc. Where platy or prismatic rock fragments are present the rock type or structure controlling the shape such as bedding, cleavage, schistosity, etc., should be given as well as degree of rounding.

**Mineral Composition.**--The mineral composition of site materials varies greatly from place to place, depending upon the genesis of the materials and the geologic processes involved. The mineral composition varies also in respect to particle sizes at a particular site. Thus the proportion of platy minerals increases over equidimensional minerals as the particle size decreases.

The coarse-grained materials are normally dominated by those rock-forming minerals which are more resistant to chemical weathering such as quartz, the heavy minerals and fresh rock-forming minerals such as feldspar, calcite, and mica. The fine-grained materials may be dominated by clay minerals representing the products of chemical weathering. Identification of the mineral composition of clays and the finer fractions of silts require X-ray diffraction or differential thermal analysis, neither of which is practical for field use. The geologist is, therefore, limited in identification of these materials to such tests as the use of benzidine for montmorillonite, etc., (see Page 2-13). Additional descriptions based on dilatancy, plasticity, etc., should be made.

The mineral composition of the less complex minerals in the coarse-grained fractions, however, can readily be identified by megascopic methods. Wherever this is possible the predominant rock or mineral constituents and those rocks and minerals having a deleterious effect on engineering properties should be noted using standard geologic terms. Oftentimes broad classifications, such as "igneous", and "metamorphic" may suffice for descriptions for engineering purposes where more detailed descriptions are not needed for correlation purposes or where materials would have little effect on the engineering properties.

**Hardness.**--The hardness of individual particles of minerals is normally expressed by geologists by means of the Moh scale. Hardness, along with color, streak, crystal form, specific gravity, etc., is an important property for identification of minerals.

#### Mass Characteristics.

Although individual particle characteristics are important for identification purposes and have an influence on engineering properties, associations of different particles impart mass characteristics and properties which are entirely different from those of the individual particles. This section briefly outlines mass characteristics which need to be described to develop adequate interpretations for geologic and engineering purposes.

**Texture and Gradation.**--The term "texture" is used normally to describe indurated rocks. Texture is defined as the geometrical aspects of the component particles of a rock, including size, shape, and spatial arrangement. Texture in unconsolidated materials refers essentially to grain size distribution. Texture is important for field identification purposes and for predicting behavior of rock and soil under load. Although specific geologic terms such as phaneritic, aphanitic, and porphyritic imply specific descriptions of igneous rock, simpler terms such as "coarse-grained", "fine-grained", and "glassy", can often be

employed to be more understandable. It is often more important to describe the presence of mineral constituents, such as serpentine and mica, which are hazardous to construction than to identify the type of rock. The symbols for rock contained in Figure 2-2 "Standard SCS Geologic Symbols" constitute a coverage normally adequate for classifying and describing rocks.

The structure of rocks can usually be described in a few simple terms such as holes, cavities, joints, bedding planes, fractures, cleavage, and schistosity. Use of terms such as vesicular, vugs, etc., are confusing to engineers not well versed in geologic terminology and should be avoided where possible and always defined when used.

The term gradation is used here to describe the relative distribution of various grade sizes in unconsolidated or soil materials in keeping with engineering terminology. In the Unified System, the grain size distribution within the clay and silt fraction is determined on the basis of behavior characteristics rather than grain-size diameter. The classification system is based on groupings of grain sizes which impart specific engineering characteristics to the materials. The use of this system is not entirely adequate to define all physical characteristics for identification and correlation purposes.

The system to be used for geologic purposes consists of 22 classifications based primarily on the relative proportions of gravel, sand, silt and clay portions. These classifications are outlined in Figure 2-2.

**Hardness, Cementation and Consolidation.**--The term hardness as used in this guide applies to classification of hardness of strata rather than individual minerals. Hardness is influenced by mineralogical composition, shape of grains, consolidation, cementation and other factors. Hardness is an important factor to be considered in identification and correlation of strata and, together with other geologic factors such as stratification, fracturing, weathering, and lamination, has an influence on such engineering characteristics as bearing capacity and workability (ease of excavation).

One of the more important factors influencing hardness of materials is cementation. This is of primary importance, not only for determining hardness, but also in determining durability of rock for engineering purposes. The principal cementing materials are clays, calcium carbonate, iron oxide and silica. Most durable, of course, are bonds formed by siliceous cementation whereas clay bonds are least durable and subject to slaking when exposed to air or water. It is important, therefore, in descriptions of hardness, that the type of cementation be included. The following scale of hardness may be used for describing hardness characteristics of materials:

**Hardness 1.**--Permits denting by moderate pressure of the fingers. It is typical of soil formations in which practically no cementation has occurred.

**Hardness 2.**--Resists denting by the fingers, but can be abraded and pierced to shallow depths by a pencil point.

# STANDARD SCS GEOLOGIC SYMBOLS

2-7

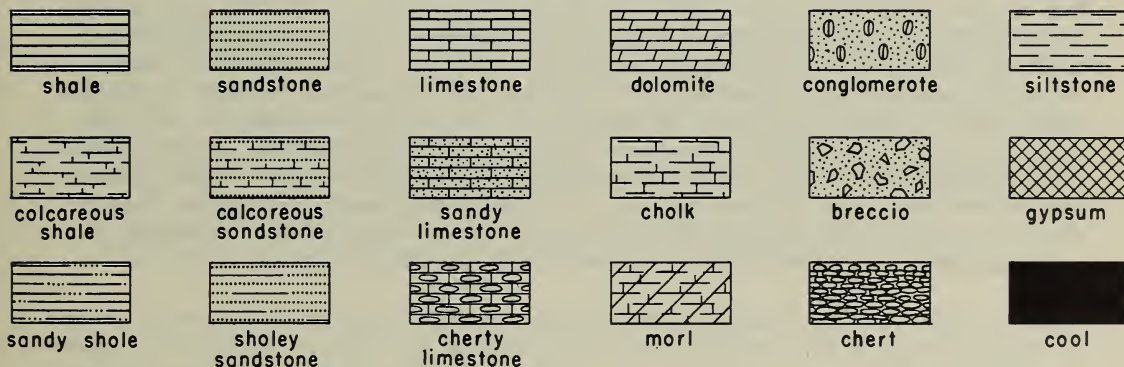
## UNCONSOLIDATED MATERIALS



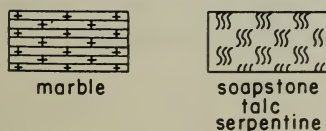
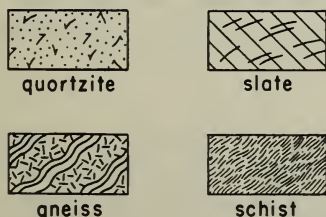
\* To be added to Standard Symbol when significant amounts of dispersed gypsum or calcified zones are present in the section.

## CONSOLIDATED MATERIALS

### SEDIMENTARY ROCKS



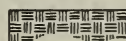
### METAMORPHIC ROCKS



### IGNEOUS ROCKS



### UNDIFFERENTIATED



● unsampled test hole location

⊙ sampled test hole location

Figure 2-2 Standard SCS Geologic Symbols

Hardness 3.--Resists a pencil point, but can be scratched and cut with a knife blade.

Hardness 4.--Resistant to abrasion or cutting by blade of a knife but can be easily dented or broken by light blows of a hammer.

Hardness 5.--Can be deformed or broken by repeated moderate hammer blows.

Hardness 6.--Can only be broken by heavy, and in some rocks, repeated hammer blows.

The foregoing scale of hardness, is useful for determining workability. Formations rated as having a Hardness 1 and 2 can be excavated by shovels or bulldozers in practically all cases if the entire excavation is in the formation. Formations having Hardness 3 in most cases can be excavated by power shovels; and heavy power shovels can excavate formations having Hardness 4. Formations of Hardness 3 and 4 have some degree of cementation and include partly cemented sandstones and marls and fairly compact shales. Most formations having Hardness 5 and all those having Hardness 6 must be removed by blasting if they have considerable bulk or thickness.

At least two other geologic factors must be considered in relating rock hardness to difficulty of excavation. These are the thickness and character of the individual beds and the presence or absence of such structural elements as joints, fractures, and rock cleavage. It must be recognized that thin beds of a relatively hard rock, such as a well-cemented sandstone or crystalline limestone of Hardness 5 or 6 may be removed by ripper, rock plow or power shovel if it occurs in beds no more than 6 or 8 inches thick or if it is highly jointed. Hence, a series of medium or soft shales with interbedded 6-inch layers of hard limestone (Hardness 5 or 6) usually can be removed with a power shovel. On the other hand, a massive bed of shale or crystalline gypsum 6 feet or more thick may require blasting although neither stratum would be rated higher than Hardness 3.

Color.--Color varies widely in materials but often provides a useful means of identification for geologic and engineering purposes. Thus the presence of organic matter can often be readily detected by color. In classifying color of materials, care should be used to determine whether the coloring is due to inherent color of constituents, superficial stain or tarnish, or a weathering product. There is a marked difference of color depending on whether the material is dry or wet.

#### Stratigraphy.

Stratigraphy of the site, treats of the origin, mode of deposition, composition, sequence, character, thickness, continuity, age and correlation of the geologic materials. Knowledge of stratigraphy aids in the interpretation of conditions of water movement and the performance of the foundation materials under conditions of loading. Stratigraphy of the site may also strongly influence selection of practical construction methods.

Stratigraphy of the site is established from the study of particle and bulk characteristics and the interpretation and extrapolation of the boring and test hole data. The accuracy of stratigraphic interpretations is most important in the development of a practical and economic design of the structure. Errors may result in costly delays requiring re-design of the structure and alteration of construction methods.

The determination of stratigraphy involves consideration of particle characteristics, their origin, mode of transportation (wind, water, ice, gravity) and the processes of deposition and consolidation. Guiding factors are the petrographic characteristics of the materials; e.g., mineral composition, size, shape, and spatial arrangement of the particles; and the type, age, depth, thickness and continuity of the deposit.

**Type of Deposit.**--Type of deposit involves the mode, agent, and process of formation and furnishes information on continuity of strata and uniformity of physical characteristics which may be encountered. For example, deposits of loess and glacial lake deposits (varved clays) are remarkably consistent in thickness of strata, and physical characteristics of materials. Other types such as stream (fluvial) deposits may pinch out in a matter of a few feet and the particle characteristics may vary widely over short distances. It is important, therefore, that the type of deposit be accurately described.

Standard geologic terms, simplified to the extent possible for adequate interpretations should be used to describe the type of deposit. Such terms as granite, volcanic ash, marl, limestone, gneiss, etc., along with the formation name or age are commonly used to describe such rock materials. Because of the highly variable characteristics of sediments, however, a greater breakdown of terms which imply mode of origin are to be employed. The following is a check list of genetic descriptive terms for the more important modes of origin of sedimentary deposits usually encountered in dam-site investigations.

#### I. Formed in place

A. Residual soil

B. Weathered rock

#### II. Transported and deposited

A. Gravity

1. Earth slip or slump

2. Rock slide

3. Talus

4. Mudflows

5. Colluvial deposits (soil creep aided by sheet wash)

B. Windblown

1. Dune sand
2. Sand drift
3. Loess

C. Glacial

1. Till, (sheet, drift, moraine, drumlin, etc.)
2. Outwash
3. Kame
4. Esker

D. Lake and Marine Deposits

1. Quiet water
  - a. Lacustrine
  - b. Marine
2. Near shore deposits due to wave action
  - a. Beach
  - b. Cusps
  - c. Bars
  - d. Barriers
  - e. Keys and cays

3. Stream-lake (or estuarian) deposits

Deltas

E. Stream deposits

1. Alluvial fan
2. Alluvial floodplain
3. Channel deposits

Point bars

4. Levees

**Age.**--The age of a stratum establishes its vertical position in the geologic column and its relationship in respect to other strata. Age should always be indicated using standard geologic periods and epochs when identifiable.

**Depth, Thickness, and Continuity.**--The depth and thickness of materials at specific points at a site are determined from exposures and sub-surface boring or test holes. The areal continuity must be interpreted on the basis of depth, thickness, type, and similarity of deposits and particle and bulk characteristics measured and described at different observation points. To facilitate interpretation of areal continuity all measurements of depth should be referenced to a common elevation based either on mean sea level or an assumed datum plane. It is important that the vertical and areal continuity be determined for those materials which may have an effect on the design and construction of a dam. Continuity is best established on a graphic basis. Depth and thickness of identified strata are to be plotted on graph paper at their proper elevations. Continuity lines are to be drawn in (dashed) to correlate with similar strata. Forms SCS-35A; 35B, and 35C, "Plan and Profiles for Geologic Investigations" are provided for this purpose. For examples, see Chapter 7, Figures 7-2, 7-3, and 7-4. If a stratum in the vertical column of one observation cannot be correlated with any stratum in the next column, continuity has not been established. If correct interpretations have been made, the particular stratum is considered discontinuous. This is a common occurrence in types of materials having lenticular beds or where faults or other structural movements have resulted in shifting of beds to positions where they are not concordant. Whenever the limits of continuity cannot be established and the discontinuity cannot be accounted for in interpretations, additional observations are needed until sufficient exploration has been done to establish lateral and longitudinal continuity.

### Structure.

The geologic structure of the site is of primary consideration in site selection. The term "structure", as applied to the geology of a dam site, refers to all of the geologic structural features either at the dam site or influencing the site. These features include faults, folds, joints, fractures, etc. Structure has an important influence on the geologic conditions of a site and the ultimate stability and safety of an engineering structure. Problems of leakage, sliding of embankments, uplift pressure in foundations, differential settlement, etc., are often traced back to inadequate delineation and consideration of the geologic structure at the site.

**Attitude.**--Attitude implies the geometric alignment of strata, faults, fractures, etc., and in this respect is synonymous with the terms dip and strike which are normally restricted to use in describing orientation of strata. In some instances, such as in plunging anticlines, for example, special conditions require more elaborate descriptions than dip and strike. In describing attitude, standard terms should be used.

**Folds.**--A common type of deformation in the earth's surface is folding. Normally folds extend over larger areas so that deformation at a particular site results in more or less consistency of dip and strike and the fold itself escapes detection. In these instances they have an influence on the nature of fractures as well as attitude of strata. Minor folds, however, are usually of more concern than those of regional character. Small folds, with capacity for substantial subterranean flowage may escape detection in a geologic investigation of a dam site. Where such folds are suspected and anomalies of continuity in respect to apparent inclination of strata in bore holes are encountered, additional borings may be required to determine the location and size of the folds for design considerations. Descriptions of folds should indicate their size, location, type (anticlines, synclines) and the dip and strike of the limbs and axial plane.

**Faults.**--A fault is defined as a break in the earth's crust along which movement has taken or is taking place. Displacement may be but a few inches or many miles. Faults may be detected by discontinuity of strata and by surface features. Aerial photographs often provide positive evidence of the presence of faults in an area. Inactive faults are important from the standpoint of influencing water movement and differential settlement if strata of contrasting bearing capacity are brought adjacent to each other. Faults encountered at sites should be described in detail including alignment, type (normal or reverse) and the throw, dip slip, net slip, heave and strike. Where displacement of strata has occurred which results in the bringing of strata of different bearing capacity to the same plane, details of this should be included in the descriptions of faults. Furthermore, the fault zone is of special consideration if appreciable alteration of minerals has occurred, shattering is encountered, or if appreciable gouge is present. In these instances the approximate dimensions of the fault zone should be determined and changes in character of materials described. Active faults are important for obvious reasons.

**Joints.**--Joints are defined as breaks in the earth's crust along which no appreciable displacement of strata has occurred. They are important because they may allow movement of groundwater and thereby create problems of leakage, uplift pressures, etc. The number and orientation of joint systems and their spacing is of primary concern since they influence stability of foundation, movement of groundwater and ease of rock excavation. Jointing in shale may induce permeability and cause high infiltration rates. Description of joints should include, besides their attitude, the type of joint (strike, dip, or oblique) and the joint system (set and/or conjugate).

#### Paleontology.

Evidences of life in the past are important for correlation purposes to establish continuity. Fossils are keys to correlation of rock strata. The presence of artifacts may be a means of distinguishing between Recent and Modern sediments. Formations composed entirely of plant and animal remains may have a very marked, usually adverse, influence on engineering properties. Thus peat, muck, and carbonized plant remains have little value as construction materials. Foraminifera tests, algae, coral and other components impart specific behavior characteristics to engineering materials. Descriptions of artifacts and fossils where they have little

or no influence on the engineering properties of materials should be limited to brief notes needed for correlation purposes. More detailed descriptions are needed where such materials have an influence on the engineering properties. These should include description of the nature of materials, including name, their extent and distribution in the formation.

#### Field Classification.

The foregoing discussion has outlined descriptions of materials which need to be developed to properly log materials for geologic purposes. They include physical characteristics which are needed for design and construction purposes since the Unified Soil Classification is limited in extent and application. In addition to these descriptions the geologist may need to make additional field tests to classify materials more accurately. These may include streak tests, use of dilute hydrochloric acid tests for identification of calcareous constituents; acetone test for detection of gypsum, water tests to determine slaking characteristics, etc., to improve his descriptions and complete his logs. Most of these tests are well known to geologists. The following tests are some which are less well known:

Benzidine Test: A saturated water solution of the organic compound benzidine (or benzidine hydrochloride) produces a blue coloration in contact with clay minerals of the montmorillonite and illite groups, although the benzidine solution itself is slightly pink. The sample is not to be treated with hydrochloric acid before application of the stain. Manganese dioxide and organic materials may cause blue coloration in the absence of bentonite. Reducing agents (ferrous iron and others) sometimes prevent development of coloration. Gypsum greatly affects this test, but the influence may be cancelled out by first boiling the sample in water, pouring off the fine fraction, drying at 110°C., and finally staining.

Crystal Violet Test: The crystal-violet staining solution causes montmorillonite to appear green at first and then change to a greenish yellow or orange yellow. The sample must be treated with hydrochloric acid prior to applying the stain. With this test illite attains a quite dark green color. Kaolin merely absorbs the violet dye. The test solution consists of 25 cc of nitrobenzene and 0.1 gram of crystal violet.

Malachite-Green Test: Clay minerals of the kaolinite group (when treated with hydrochloric acid) show a bright apple-green color after application of malachite green solution. The solution consists of 25 cc of nitrobenzene and 0.1 gram malachite green. Montmorillonite and illite clays usually show greenish yellow or pale yellow.

The geologic classification of materials in graphic form for Service work has been standardized by development of symbols for unconsolidated (soil) and consolidated (rock) materials. Standard symbols are shown in Figure 2-2. Lumerith stick-ups of the various symbols are

available from the Cartographic Unit serving each area to facilitate preparation of geologic columns.

### Unified Soil Classification System

#### Purpose and Scope.

The Unified Soil Classification System provides a method of grouping earth materials according to their engineering properties. It is based on soil behavior, which is a reflection of the physical properties of the soil and its constituents.

For the purpose of classification the system establishes 15 soil groups, each having distinctive engineering properties. Boundary classifications are provided for soils which have characteristics of two groups.

The system provides for both a simple visual and manual method and a laboratory method for determining the amount and type of basic constituents of the soil. Both methods are based on gradation and plasticity and vary only in degree of accuracy.

Letter symbols have been devised which are derived from terms which are descriptive of the soil components, gradation and liquid limit. These are combined to identify each of the 15 soil groups. Table 2-2 lists these symbols and gives the name with which each is associated.

Table 2-2

#### Letter Symbol and Names

<u>Letter Symbol</u>	<u>Name</u>	<u>Letter Symbol</u>	<u>Name</u>
None	Boulders	O	Organic
None	Cobbles	Pt	Peat
G	Gravel	W	Well graded
S	Sand	P	Poorly graded
M	Silt	H	High liquid limit
C	Clay	L	Low liquid limit

#### Soil Components.

The term "soil components" has been given to the solid mineral grains of which earth materials are composed. They range in size from over 12 inches average diameter to colloidal size. The size, gradation, shape, and mineral composition affect the behavior of the soil, as do the moisture content and the inclusion of other materials such as organic matter, gases and coatings of cementing minerals. Table 2-3 lists the soil components, giving their grain sizes and descriptions and enumerating some of their significant

Table 2-3  
Soil Components and Significant Properties <sup>1/</sup>

Soil Component	Symbol	Grain size range and description	Significant properties
Boulder	None	Rounded to angular, bulky, hard, rock particle, average diameter more than 12 in.	Boulders and cobbles are very stable components, used for fills, ballast, and to stabilize slopes (riprap). Because of size and weight, their occurrence in natural deposits tends to improve the stability of foundations. Angularity of particles increases stability.
Cobble	None	Rounded to angular, bulky, hard, rock particle, average diameter smaller than 12 in. but larger than 3 in.	
Gravel	G	Rounded to angular, bulky, hard, rock particle, passing 3-in. sieve (76.2 mm) retained on No. 4 sieve, (4.76 mm).	Gravel and sand have essentially same engineering properties differing mainly in degree. The No. 4 sieve is arbitrary division, and does not correspond to significant change in properties. They are easy to compact, little affected by moisture, not subject to frost action. Gravels are generally more pervious, stable, and resistant to erosion and piping than are sands. The well-graded sands and gravels are generally less pervious and more stable than those which are poorly graded. Irregularity of particles increases the stability slightly. Finer, uniform sand approaches the characteristics of silt; i.e., decrease in permeability and reduction in stability with increase in moisture.
Coarse		3 - 3/4 in.	
Fine		3/4 in. to No. 4 sieve (4.76 mm).	
Sand	S	Rounded to angular, bulky, hard, rock particle, passing No. 4 sieve (4.76 mm) retained on No. 200 sieve (0.074 mm).	
Coarse		No. 4 to 10 sieves: 4.76 to 2.0 mm.	
Medium		No. 10 to 40 sieves: 2.0 to 0.42 mm.	
Fine		No. 40 to 200 sieves: 0.42 to 0.074 mm.	
Silt	M	Particles smaller than No. 200 sieve (0.074 mm) identified by behavior; that is, slightly or non-plastic regardless of moisture and exhibits little or no strength when air dried.	Silt is inherently unstable, particularly when moisture is increased, with a tendency to become quick when saturated. It is relatively impervious, difficult to compact, highly susceptible to frost heave, easily erodible and subject to piping and boiling. Bulky grains reduce compressibility; flaky grains, i.e., mica, diatoms, increase compressibility, produce an "elastic" silt.
Clay	C	Particles smaller than No. 200 sieve (0.074 mm) identified by behavior; that is, it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried.	The distinguishing characteristic of clay is cohesion or cohesive strength, which increases with decrease in moisture. The permeability of clay is very low. It is difficult to compact when wet and impossible to drain by ordinary means, when compacted is resistant to erosion and piping, is not susceptible to frost heave, is subject to expansion and shrinkage with changes in moisture. The properties are influenced not only by the size and shape, (flat, plate-like particles), but also by their mineral composition; i.e., the type of clay-mineral, and chemical environment or base exchange capacity. In general, the montmorillonite clay minerals have greatest, and kaolinite the least adverse effect on the properties of soils.
Organic Matter	O	Organic matter in various sizes and stages of decomposition.	Organic matter present in even moderate amounts increases the compressibility and reduces the stability of the fine-grained components. It also may decay, causing voids, or by chemical alteration change the properties of a soil. Hence organic soils are not desirable for engineering uses.

<sup>1/</sup> Adopted from Use of the Unified Soil Classification System by the Bureau of Reclamation, A. A. Wagner, Fourth International Conference on Soil Mechanics and Foundations, London, England, August 1957.

properties. For field identification purposes, 1/4 inch is assumed to be equivalent to the No. 4 sieve and the No. 200 sieve size is about the smallest particle visible to the naked eye. The No. 40 sieve size was chosen as the limit between medium and fine sand because "Atterberg limits" tests are performed on the fraction finer than the No. 40 sieve size in the laboratory.

#### Gradation.

Well graded.--Soils which have a wide range of particle sizes and a good representation of all particle sizes between the largest and the smallest present are said to be well graded.

Poorly graded.--Soils in which most particles are about the same size or have a range of sizes with intermediate sizes missing are said to be poorly graded.

The gradation or grain-size distribution of soils consisting mainly of coarse grains is diagnostic of the physical properties of the soil. However, gradation is much less significant for predominately fine-grained soils.

In the laboratory the amounts of the various sized grains can be determined by sieving and wet mechanical analysis and the type of gradation determined by the shape of the grain-size curve. Figure 2-3 illustrates the grain-size distribution graphs of some typical soils. Poorly graded soils have steeply sloping, and often abrupt changes in curves when plotted on the standard grain-size distribution forms (SCS-353).

The coefficient of uniformity ( $C_u$ ) (measure of size range) of a given sample is the ratio of that size, of which 60 percent of the sample is finer ( $D_{60}$ ); to that size, of which 10 percent of the sample is finer ( $D_{10}$ ). The coefficient of the curvature ( $C_c$ ), which defines the shape of the grain-size curve, is the ratio of the square of that size, of which 30 percent of the sample is finer ( $D_{30}$ ), to the product of the  $D_{60}$  and  $D_{10}$  sizes. These ratios can be simply rewritten.

$$C_u = \frac{D_{60}}{D_{10}} \qquad C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$$

See Figure 2-4 for explanation of the use of these coefficients and other criteria for laboratory identification procedures.

#### Consistency.

The most conspicuous physical property of the fine-grained soils is their plasticity or lack thereof (consistency). The various stages of consistency have been described in Chapter 1 under Engineering Properties of Earth Materials. Atterberg tests are used to determine the liquid limit of soils in the laboratory. The plastic limit is determined by means of a standard thread test (see Figure 2-5). Field tests for dilatancy (reaction to shaking), dry strength (crushing characteristics), and toughness (consistency near the plastic limit) have been devised for field determinations. Table 2-4 contains the procedures for making these field determinations and the methods of field classifications. These tests are illustrated in Figure 2-5.



Figure 2-4 Laboratory Classification in the Unified System

Fractions			Group Symbols	Laboratory classification criteria	
Coarse grained soils More than half of material is larger than No. 200 sieve size	Gravels More than half of coarse fraction is larger than No. 4 sieve size	Clean gravels (little or no fines)	GW	$U_1 = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		Gravels with (appreciable amount of fines)	GP	Not meeting all gradation requirements for GW	
		Clean sands (little or no fines)	GM	Atterberg limits below "A" line, or PI less than 4	
		Sands with fines (appreciable amount of fines)	GC	Atterberg limits above "A" line, with PI greater than 7	
	Sands More than half of coarse fraction is smaller than No. 4 sieve size	Clean sands (little or no fines)	SW	$U_1 = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		Sands with fines (appreciable amount of fines)	SP	Not meeting all gradation requirements for SW	
			SM	Atterberg limits below "A" line or PI less than 4	
			SC	Atterberg limits above "A" line, with PI greater than 7	
Fine grained soils More than half of material is smaller than No. 200 sieve size	Silts and clays liquid limit less than 50		ML	<p>Comparing soils at equal liquid limit Toughness and dry strength increase with increasing plasticity index</p> <p>Plasticity index</p> <p>Liquid limit</p> <p>Plasticity chart for laboratory classification of fine grained soils</p>	
			CL		
			OL		
	Silts and clays liquid limit greater than 50		MH		
			CH		
			OH		
	Highly organic soils		Pt		

Corps of Engineers, U. S. Army, Tech. Memo No. 3-357, March, 1953 and Use of the Unified Soil Classification System by the Bureau of Reclamation, A. A. Wagner, Fourth International Conference on Soil Mechanics and Foundations, London, England, August 1957.

Table 2-4

Op. cit. p. 2-18

Unified soil classification (including identification and description)				Field identification procedures		Group symbols	Typical names	Information required for describing soils	Field identification procedures for fine grained soils or fractions
				(Excluding particles larger than 3 in. and basing fractions on estimated weights)	(Excluding particles larger than 3 in. and basing fractions on estimated weights)				
Coarse grained soils More than half of material is larger than No. 200 sieve size 1/2	Gravels More than half of coarse fraction is larger than No. 4 sieve size 1/4	Sands More than half of coarse fraction is smaller than No. 4 sieve size 1/4	Amount of fines (Clean sands (little or no fines) or no fines)	Field identification procedures (for identification of soils, see ML below)	Field identification procedures (for identification of soils, see ML below)	Group symbols	Typical names	Information required for describing soils	Field identification procedures for fine grained soils or fractions
Fine grained soils More than half of material is smaller than No. 200 sieve size	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	SP	Poorly graded sands, gravelly sands, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name, and other pertinent descriptive information; and symbol	These procedures are to be performed on the minus No. 40 sieve size screening, approximately 1/64 in. For field classification purposes screening is not intended, simply remove by hand the coarse particles that interfere with the tests. Dilatancy (reaction to shaking): After removing particles larger than No. 40 sieve, prepare a pat of moist soil the size of about one-half cubic inch. Add water to the soil until it is just moist. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a lumpy consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil. Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts show a moderately quick reaction. Dry Strength (Crushing characteristic): After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity. A high dry strength is characteristic for clays of the CH group. A plastic inorganic silt possesses only very slight dry strength. Silty fine sand and silt possess the same slight dry strength but can be distinguished by the feel when molding the tested specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.
Highly organic soils spongy feel and frequently by fibrous texture	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size; rounded and subangular sand grains coarse to medium with low dry strength; well compacted and moist in place; alluvial sand; (SM)	SP	Poorly graded sands, gravelly sands, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name, and other pertinent descriptive information; and symbol	These procedures are to be performed on the minus No. 40 sieve size screening, approximately 1/64 in. For field classification purposes screening is not intended, simply remove by hand the coarse particles that interfere with the tests. Dilatancy (reaction to shaking): After removing particles larger than No. 40 sieve, prepare a pat of moist soil the size of about one-half cubic inch. Add water to the soil until it is just moist. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a lumpy consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil. Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts show a moderately quick reaction. Dry Strength (Crushing characteristic): After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity. A high dry strength is characteristic for clays of the CH group. A plastic inorganic silt possesses only very slight dry strength. Silty fine sand and silt possess the same slight dry strength but can be distinguished by the feel when molding the tested specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

1/ Boundary classifications - Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GM-CC, well graded gravel-sand mixture with clay binder.

2/ All sieve sizes on this chart are U. S. standard.

Dilatancy Test



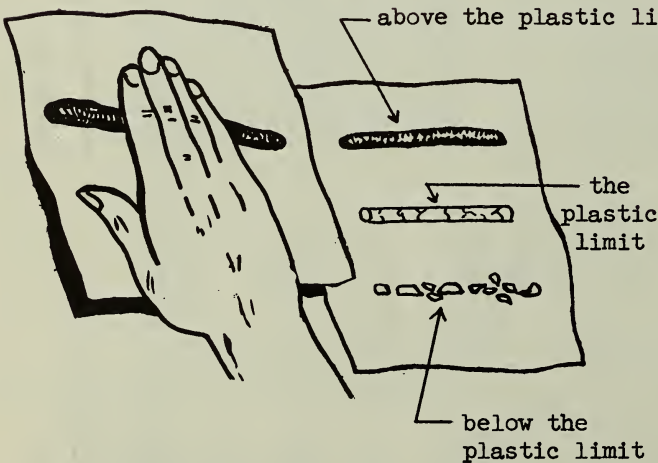
Shaking wet soil

Dry Strength Test



Crumbling dry sample between fingers

Toughness Test



Rolling soil into threads



Remolding tough thread at plastic limit into lump and deforming

Figure 2-5 Field Tests

### Field Classification.

An adequate description of the soil material encountered in a geologic investigation is of extreme importance. Such characteristics as approximate percentage of sizes, maximum size, shape, and hardness of coarse grains; geologic structure; cementation; dispersion; moisture and drainage conditions; organic content; color; plasticity; and degree of compaction; in addition to typical name and group symbol, should be recorded in accurate and precise but simple terms. Local or geologic names should also be included where possible.

The field procedure does not require specialized equipment. A supply of clear water in a syringe or oil can and small bottles of dilute hydrochloric acid, acetone and benzidine and other reagents will facilitate the work. The geologist who lacks experience in classifying materials in the Unified System will find it expedient to use a No. 4, a No. 10, and a No. 200 Tyler sieve in the field in the initial stages of training to aid him in identifying relative quantities of coarse and fine-grained samples. Identification without aid of sieves becomes relatively easy with practice and experience. A pocket penetrometer is also helpful in identifying hardness of materials.

A representative sample is required. The average size of the largest particle is estimated. The boulders and cobbles, those particles which are larger than 3 inches in average diameter, are removed and the amount, percentage by weight, in the total sample is estimated and recorded. The amount of over-sized material may be of importance in the selection of sources for embankment material. The distribution occurrence, and estimate of the percentage of boulders and cobbles in a foundation should be noted so that their effect on the physical properties of the materials and possible construction problems can be evaluated. The rest of the procedure is, in effect, a process of simple elimination. The following step-by-step procedure should be used:

Step 1.--Spread the sample on a flat surface or in the palm of the hand to aid in observing the relative amounts of coarse and fine-grained components. Classify the soil as coarse-grained or fine-grained.

Step 2.--If fine-grained, see Step 6 below. If coarse-grained, classify gravel or sand, e.g., it would be classified as gravel if more than 50 percent is larger than No. 4 sieve (about 1/4 inch) and sand, if more than 50 percent is smaller than No. 4 sieve.

Step 3.--If gravel or sand, determine whether it is "clean", having less than 5 percent fines; borderline, having 5 to 12 percent fines; or "dirty", having more than 12 percent fines. Fines are defined as the fraction smaller than the 200 mesh sieve size.

Step 4.--If the gravel or sand is clean, decide if it is well-graded (W) or poorly-graded (P) and assign an appropriate group name and symbol: GW, GP, SW, or SP. Well-graded materials have a good representation of all particle sizes. Poorly-graded materials have an excess or absence of intermediate particle sizes.

Step 5.--If the gravel or sand contains appreciable fines, it is classified as GM, GC, SM, or SC, depending upon the type of fines - silt (M) or clays (C) - which are identified by the procedure for fine-grained soils; see following steps. Borderline cases, e.g., where fines range from 5 to 12 percent are to be classified with boundary symbols, thus GP-GC, SP-SC, etc.

Step 6.--For fine-grained soils or the fine-grained fraction of a coarse-grained soil the "dilatancy", "dry strength", and "toughness" tests are performed in accordance with the instructions given on the right-hand side of Table 2-4. The group name and symbol are arrived at by selection of that group, the characteristics of which most nearly compare to that of the sample. Depending upon the organic content, the fine-grained soil or the fine-grained fraction of the coarse-grained soil is classified as low to medium plasticity silt (ML), clay (CL), or organic silt or clay (OL), i.e., the liquid limit is estimated to be less than 50 percent; or plastic silt (MH), plastic clay (CH), or organic silt or clay (OH), i.e., liquid limit is estimated to be more than 50 percent.

Step 7.--Highly organic soils are classified as peat (Pt). These are identified by color, odor, spongy feel and fibrous texture.

Step 8.--Soils which have characteristics of two groups, either because of percentage of the coarse-grained components or plasticity characteristics, are given boundary classification using a name most nearly describing the soil, and the two group symbols connected by a hyphen, such as GP-GC. Boundary classifications which are common are: For the coarse-grained soils - GW-GM, GM-GP, and GM-GC; (similarly for sand). For fine-grained soils - ML-MH, CL-CH, OL-CH, CL-ML, ML-OL, CL-OL, MH-CH, MH-OL, and CH-OL; common boundary classifications between coarse and fine-grained soils - SM-ML and SC-CL.

Step 9.--Miscellaneous tests (q.v.) and criteria may be developed to identify the occurrence of other substances and constituents such as ACID TEST; reaction when dilute hydrochloric acid is applied indicates presence of calcium carbonate; ACETONE TEST for gypsum; BENZIDINE TEST FOR montmorillonite type clays (see page 2-13). A SHINE TEST; shiny surface when dry or moist soil cut with a knife indicates plastic clay and TASTE TEST; adherence of a dry pat of fine-grained soil when touched to tongue indicates a high clay content. Heating sometimes intensifies organic odors.

Table 2-5, Field Identification Criteria, lists in tabular form the classification characteristics of the soil groups. The engineering geologist can only estimate the primary constituents of unconsolidated material in the Unified System. More exact mechanical analyses must be made in the laboratory. However, when the laboratory analyses become available, they should be compared with the original field estimates. In this way the geologist can improve the accuracy of his estimates.

Table 2-5

## FIELD IDENTIFICATION CRITERIA

## CLASSIFICATION CHARACTERISTICS - FINE GRAIN

Classification	Dilatance (Shaking)	Dry Strength (Crushing)	Toughness (Plasticity)	Ribbon	Shine	Odor
ML Fine Fraction of SM	Rapid	Slight	Low	None	Dull	
CL Fine Fraction of SC	Slow	High	Medium	Weak	Dull	
OL	None	Medium	Low	None	Dull to Slight	Pronounced
MH	Very Slow to None	Medium	Medium	Weak	Slight Shine	
CH	None	High	High	Strong	Shiny	
OH	None	High	Low	Weak	Dull to Slight	Pronounced

## CLASSIFICATION CHARACTERISTICS - COARSE GRAIN

GW	<u>GRAVELS</u> More than 1/2 of the coarse frac- tion is larger than No. 4 size	Clean Gravels Little or No Fines	Well Graded Gravels and Gravel Sand Mixtures
		Gravels with Fines	Poorly Graded Gravels and Gravel Sand Mixtures
GP			
GM			Silty Gravels
GC			Clayey Gravels
SW		Clean Sands	Well Graded Sands
SP			Poorly Graded Sands
SM	<u>SANDS</u> More than 1/2 of the coarse frac- tion is finer than No. 4 size	Sands with Fines	Silty Sands - (Fines are Classified ML)
SC			Clayey Sands - (Fines are Classified CL)



## CHAPTER 3. REQUIREMENTS FOR GEOLOGIC INVESTIGATIONS AND SAMPLING

### General

Requirements for design and construction vary widely depending upon such conditions as the size and purpose of the structure, kinds of construction materials, site conditions, and economic and safety considerations. Since site investigations and soil mechanics tests are geared to requirements for design and construction, it is obvious that the intensity of site investigations and the kinds of samples to be taken will vary from site to site. Minimum requirements have been established for specific conditions to assure that site investigations and materials sampling meet acceptable standards for Service work.

This chapter outlines the minimum requirements for intensity of geologic investigation and the sampling for soil mechanics tests. It should not be inferred that establishment of these requirements sets the pattern of investigations and sampling to meet all site conditions. Intensity of investigation and sampling must be established on the basis of each structure and each structure site.

### Minimum Requirements for Geologic Investigations

Minimum requirements for geologic investigations of dam sites have been established in Engineering Memorandum SCS-33. The following excerpts outline these requirements:

I. GENERAL.--A preliminary examination should be made of all structure sites to determine geologic conditions and characteristics of materials (both consolidated and unconsolidated), pertinent to design. This examination should be made regardless of purpose of the structure, source of funds, or contractor. Detailed, subsurface exploration or collection and testing of samples may not be required for small, no-hazard, structures such as farm ponds, drop structures, chutes, etc., to be built in areas of generally homogeneous materials. In such cases, the engineering characteristics of the material at the site need only to be recognized and evaluated on the basis of experience in the area. Under such circumstances, it will not be necessary for a geologist to visit the site to confirm geologic conditions.

II. PRELIMINARY GEOLOGIC EXAMINATION.--A preliminary, or surface examination, should be made of every site where a structure is planned. The preliminary examination should include a thorough inspection of outcrops, cut banks and other surface exposures; erosion conditions, landslides, seeps, and springs; and other pertinent conditions in and adjacent to the watershed to obtain the basic information needed to evaluate the geologic conditions and character of materials at the site.

The purpose of the preliminary examination is to establish the geologic feasibility and the extent and precision of a detailed

subsurface investigation that may be required. In some instances the preliminary examination, in itself, may be adequate to determine geologic conditions and engineering characteristics of materials. In other cases, information on subsurface materials at the site may be obtained during the preliminary examination stage from test pits, hand auger borings, trenching or other methods, so that a subsequent detailed subsurface investigation will not be required. Where the preliminary examination reveals that a detailed subsurface investigation is required, the preliminary examination provides a basis for planning the detailed investigation. Planning the detailed investigation requires consideration of such items as depth, number and location of borings, kinds and locations of samples to be taken, equipment required, requirements for clearing, staking and mapping the site, need for access roads, etc.

III. DETAILED SUBSURFACE INVESTIGATION.--A detailed investigation provides information on subsurface conditions that cannot be obtained by surface examination or by shallow subsurface investigations using readily portable tools such as hand shovels and hand augers. Normally, detailed subsurface investigations require separate scheduling of equipment such as backhoes, dozers, power augers, or core drills.

Detailed subsurface investigations are required when information about the geology of the area is not adequate and/or the results of the preliminary geologic examination are not sufficiently conclusive to positively establish that:

1. Knowledge of the foundation materials and conditions, to a depth at least equal to the height of the proposed structure, is sufficient in scope and quality to serve as a basis for geologic interpretation and structural design.
2. Core and fill materials of suitable quality are available in sufficient quantity.
3. The reservoir basin of storage reservoirs is free from sinks, permeable strata, and fractures or fissures which might lead to moderate or rapid water loss.
4. Subsurface water conditions which might materially affect the design of the structure or the construction operations are known.
5. The stability characteristics of materials in the emergency or other open spillways and channels under anticipated flow conditions during operation of the structure are known.
6. The probable rate of sedimentation of the reservoir will not encroach upon the usable storage capacity in a period of years less than the designed life expectancy of the structure.

Detailed subsurface investigations shall be of sufficient intensity to determine all of the conditions or factors that may influence the design, construction, or functioning of the structure. Minimum requirements for intensity of detailed subsurface investigations are outlined in item V (see page 3-4 of this chapter). The extent and precision of the geologic investigation required for a particular proposed dam site are dependent upon (1) the complexity of site conditions, (2) the size of the structure, (3) the potential damage involved in the event of structural or functional failure, and (4) the purpose of the structure.

IV. CLASSIFICATION OF STRUCTURE SITES FOR GEOLOGIC INVESTIGATION.--The following broad groups of structure sites are established to permit association of minimum requirements for geologic investigations with maximum height of fill of the proposed dam, construction materials, purpose of structure, and the potential damage involved as defined in Engineering Memorandum No. 27, (Formerly Engineering Memorandum No. 3, Revision 2):

Group I Dam Sites.--Includes proposed structure sites for:

- a. All class (c) dams.
- b. All class (b) dams.
- c. All dams with maximum fill height of 35 feet, or greater, not included in class (b) and class (c).
- d. All structures of the following types over 20 feet maximum height: concrete or masonry arch or gravity dams, drop spillways, box inlet drop spillways, and chutes.
- e. All dams over 20 feet maximum height creating storage reservoirs for recreational, municipal water supply, or irrigation purposes where reservoirs are designed to serve more than a single landowner.

Group II Dam Sites.--Includes proposed structure sites for:

- a. All dams not included in class (c) or class (b) with maximum fill height between 25 and 35 feet.
- b. All structures of the following types between 10 and 20 feet maximum height: concrete or masonry arch or gravity dams, drop spillways, box inlet drop spillways, and chutes.
- c. All dams under 20 feet in height, creating storage reservoirs for recreational, municipal, and irrigation purposes where such reservoirs are designed to serve more than a single landowner.

Group III Dam Sites.--Includes proposed structure sites for:

- a. All other types of dams not included in group I and II above.

V. MINIMUM REQUIREMENTS FOR GEOLOGIC INVESTIGATIONS.--Site investigations in accordance with the following minimum criteria will establish an acceptable basis for design and construction, unless the geologic report \* \* \* or the results of the laboratory analyses, indicate need for further investigation. In establishing the intensity of investigations for the following group classifications, full consideration should be given to past experience in the area and the extent of geologic homogeneity that exists.

A. Group I Dam Sites.--All sites in this group should be investigated under the direction of a competent geologist of GS-9 or higher grade. This applies to the preliminary examination of the site as well as to the detailed study and subsurface exploration of the site. In all such sites subsurface exploration should be sufficiently intensive to permit the determination of:

1. The depth, thickness, continuity, relative permeability, and other pertinent characteristics of all of the materials to the specified depth beneath the base area of the dam and the centerline of any proposed outlet structure;
2. The attitude, location, extent, and character of such geologic features as folds, faults, joints, unconformities, schistosity, slaty cleavage, bedding planes, and the bedrock surface;
3. The extent and character of the unconsolidated and consolidated rock materials to be removed from the emergency or other open spillway, and the character and stability of the material in which this spillway will be constructed;
4. The depth, thickness, continuity, distribution, and engineering properties of material proposed for use as core and fill;
5. Depth to ground water.

To attain these objectives, the following is to be used as a guide to the minimum number and depth of holes (including pits or trenches) that would provide the necessary information.

Borings or pits along the centerline of earth-fill dams will have a depth of not less than the proposed height of fill unless unweathered rock is encountered. Minimum depth of borings in compressible materials, where significant surface-load influence may extend to depths greater than the height of dam, are to be determined jointly by the responsible geologist and engineer concerned. For all concrete dams, depths of borings shall be not less than 1.5 times the net height of the dam, unless unweathered rock is encountered.

Borings are to be extended far enough into unweathered rock to determine its nature and condition. All borings will be of sufficient depth to establish correlation with adjacent holes so that a complete geologic section is obtained from the elevation of the top of the proposed fill to the bottom of the deepest bore hole. The ground-water elevations in the foundation throughout the base area of the dam and abutment are to be determined. The number and spacing of holes required is largely dependent on such geologic features as regularity, continuity, and attitude of strata, and the character of geologic structures. Normally, along the centerline of the dam there should be at least five borings.

For drop inlet spillways or other pressure conduits used as outlet structures, borings shall be placed on the centerline of the outlet structure: (1) at the intersection with the centerline of the dam, (2) beneath the proposed location of the riser, and (3) beneath the downstream toe of the dam. Where rock surfaces occur close to the conduit foundation, the investigation must accurately delineate the rock elevation below the centerline of the conduit. For other types of spillways, such as drop spillways and chutes, sufficient borings must be made, and samples obtained for analysis, to permit design of a structure that will be safe insofar as bearing and sliding are concerned. The minimum depth of holes along the centerline of the outlet is to be equal to the height of the proposed fill over the outlet conduit at the location of boring, or 12 feet, whichever is greater, unless unweathered rock is encountered. The minimum depth of boring below the riser shall be 12 feet or equal to the estimated height of the riser, whichever is greater.

Where an excavated emergency spillway is planned, test borings must be of sufficient intensity to determine the quantity and character of the materials to be excavated, the limits of common and rock excavation, the suitability of the excavated material for use in construction, and erodibility of the resulting spillway channel. Each boring for emergency spillway investigations is to extend to a depth of not less than 2 feet below the bottom of the proposed emergency spillway.

The borrow area should be gridded (suggest 200-foot intervals) and initial borings taken at alternate grid intersections. Intervening borings can then be made where needed for delineation and correlation of strata. All borrow area borings should extend at least 2 feet below the expected depth of removal of material unless consolidated material which is not suitable for fill is encountered. Depth to groundwater at time of boring is to be determined, if encountered, for all borrow borings.

Hydraulic pressure testing of rock formations shall be done where leakage is suspected in such rock foundations and/or abutments of proposed dams creating storage reservoirs. Such tests are to be made at not less than 5-foot intervals in the suspected leakage zones. The test shall consist of a holding test of

1 p.s.i. per foot of depth below ground surface to be followed by a pumping test if the pressure drop in the holding test is found to exceed 10 p.s.i. per minute.

In all group I sites, it is essential that adequate samples be obtained both for field examination and for testing and analysis by the soil mechanics laboratory. This will usually include taking both undisturbed and disturbed samples of questionable unconsolidated materials. \* \* \*

B. Group II Dam Sites.—The preliminary field examination and the intensity of detailed site investigation is to be determined by a competent geologist GS-9 or higher. However, if the preliminary field examination provides positive evidence that the conditions outlined in item III are established, and if the structures involved do not require technical approval of the head of the EWP Unit, the extent of detailed site investigation needed for structures in this group may be determined by a qualified field technician who is familiar with the area.

The intensity of subsurface exploration and sampling of sites for the larger structures in the group will be similar to that carried out for group I sites, especially where the conditions in item III (see page 3-2) cannot be positively established. However, general experience in the area, existing geologic information, or the results of the preliminary geologic examination may be such that a geologist can obtain the necessary information with a less intensive program of subsurface exploration and sampling, particularly at sites for the smaller structures in this group.

C. Group III Dam Sites.—The intensity of investigation needed for group III sites can normally be determined by persons holding positions to which job approval authority for the class of structure under consideration has been delegated by State memorandum. In areas where there is little or no experience on which to base conclusions, and in areas where the geologic conditions are complex, the geologist should be consulted. The geologist is to investigate those sites in group III which require the technical approval of the head of the EWP Unit.

In respect to very small structures, consideration needs to be given to the economic feasibility of site studies. The cost of such studies should be weighed against the cost of the structure and the possible adverse effects that might result from structural or functional failure.

\* \* \*

#### Minimum Requirements for Sampling

##### General.

The intensity of sampling, like intensity of site investigations, varies with the design requirements so that minimum sampling requirements can be coordinated with the various dam site groups established for determining

the necessary intensity of geologic investigation. Responsibilities for sampling for the various group classifications are the same as those for geologic site investigations. Various types of samples are needed for soil mechanics testing. These are described briefly in the following paragraphs. Details on sampling procedures are contained in Chapters 5 and 6.

#### Disturbed Samples.

Disturbed samples are those collected by means of augers or spades, and as the name implies, a disturbed sample is one in which the natural structure, stratification, and arrangement of soil particles are destroyed or modified. They are used to make qualitative estimates of the probable behavior of materials. This type of sample is the easiest to obtain and is important for classification of materials and many soil mechanics tests. However, when quantitative information on in place strength, consolidation or permeability is needed, disturbed samples are of little value. The important consideration in respect to disturbed samples is that they be representative of the strata from which they are obtained.

#### Undisturbed Samples.

Undisturbed samples are samples taken in such a manner that the structure of original material is preserved to maximum extent possible. Undisturbed samples are used to determine shear strength, consolidation and permeability. Rock cores are used to determine strength, permeability, and weathering characteristics. Undisturbed samples are normally collected from foundation materials beneath embankments and appurtenant concrete structures when information on natural strength, consolidation or permeability is needed.

The important considerations of undisturbed samples are that they be representative and that disturbance of structure and moisture conditions of the sample be reduced to an absolute minimum. This requires close attention to proper sampling procedures, tools, packaging methods, and transportation.

#### Other Samples.

Water.--Samples of groundwater, intended for laboratory analysis, must be uncontaminated by foreign substances.

Soil Cement.--Samples are usually representative or composite selections of materials locally available and are therefore disturbed.

### Minimum Requirements of Samples Needed for Conducting Soil Mechanics Tests at the National Soil Mechanics Laboratory

#### Classification Tests.

Small samples (four-pound minimum) are needed for classification tests, for correlation of materials along the centerline or in the borrow area. Tests made on small samples include mechanical analyses, salt determination, Atterberg limits, specific gravity, and shrinkage limits.

Compaction Tests.

Large samples (25 pounds minimum) are required for moisture-density relationship (compaction) tests on borrow and spillway materials. These large borrow samples are also used to determine compacted permeability and compacted shear strength. In those areas where borrow material will probably be at field capacity or higher, a sample in an air-tight container should be sent to the laboratory for moisture content determination.

Reservoir Sealing Tests.

Large samples (25 pounds minimum) of the surface 12 inches are required for conducting reservoir sealing tests.

Soil Cement Tests.

Very large samples of 75 pounds are needed to test for soil cement or other chemical soil stabilization measures.

Direct-Shear Tests.

A representative undisturbed sample with minimum diameter of 3 inches and minimum length of 5 inches is needed to obtain the required 3 test specimens (2 1/2 inches diameter by 1 inch in length) for conducting direct shear tests.

Triaxial-Shear Tests.

A representative undisturbed sample with minimum diameter of 5 inches and a minimum length of 5 inches is needed to obtain the required 3-test specimens from the same horizon (1.4 inches diameter by 2.8 inches in length) for conducting triaxial shear tests. Where such test specimens are obtained from different horizons (uniform materials) an undisturbed core with minimum diameter of 2 inches is required.

Consolidation Tests.

A representative undisturbed sample with minimum diameter of 3 inches and minimum length of 6 inches is needed for conducting consolidation tests.

Horizontal Permeability Tests.

A representative undisturbed sample with minimum diameter of 5 inches and minimum length of 6 inches is needed to conduct horizontal permeability tests.

Rock Core Samples.

Minimum diameter of rock core samples for all tests is 2 1/8 inches.

Water Analysis.

The quantity of water required for conducting chemical analyses is one quart.

Minimum Requirements for Sampling of Dam SitesGroup I Dam Sites.

In all Group I sites, it is essential that adequate samples be obtained both for field examination and for testing and analysis by the soil mechanics laboratory. This will usually include taking both undisturbed and disturbed samples of questionable unconsolidated material and may

necessitate obtaining rock core samples from questionable consolidated materials.

Representative samples for classification of materials are to be obtained for all significantly different types of materials found in the borrow, foundation, relief well, and spillway sections of the dam for all structure sites included in Group I dam sites.

Representative samples for compaction tests are to be obtained from the borrow and emergency spillway areas of all structures in Group I-a, I-b, and I-c. Samples for compaction are to be obtained from borrow and emergency spillway areas for structures in I-d and I-e if positive knowledge based on sufficient information or experience in the area is lacking to determine behavior of materials.

Representative undisturbed samples for shear tests are to be obtained from all strata of fine-grained soils of questionable stability encountered in the foundation, within a depth equivalent to the height of the dam for all Group I-a, I-b, and I-c sites and for all dams exceeding 25 feet in height in Group I-d and I-e.

Representative undisturbed samples for consolidation tests are to be obtained from all strata of fine-grained materials of questionable stability encountered in the foundation within a depth equivalent to the height of the dam, and depths greater than the height of dam if bottomed in compressible materials for all I-a, I-b, and I-c sites. Such samples are also to be obtained for highly questionable materials of low shear strength such as soft clays and soft silts, in the foundations of dams exceeding 25 feet in height in Group I-d and I-e.

Occasionally, representative undisturbed samples for horizontal permeability tests of GW-GP and SW-SP materials for sites in this group will be needed for highly complex permeability and water table conditions which require evaluation for uplift pressures, relief wells, blankets, and other considerations of design. However, better results will be obtained by in-place tests of some materials such as gravel.

Samples of water for chemical analyses are to be taken of all supplies to be used for construction of embankment or concrete appurtenances for Group I dam sites when such water is suspected of containing high concentrations of salts, particularly sulphates, alkalies, and humic and other acids which would have a deleterious effect on construction materials.

Samples of all materials proposed for stabilization by soil-cement or chemical methods are to be taken for all Group I dam sites.

Samples of reservoir and abutment materials for determining reservoir sealing requirements are to be obtained for all sites in this group where storage other than sediment pool storage is to be incorporated in the design and where moderate or serious leakage is suspected.

#### Group II Dam Sites.

Representative samples for classification of materials are to be obtained for all types of materials found in the borrow, emergency spillway, foundation and relief well sections of all dam sites in this group.

Representative samples for compaction tests are to be obtained from the borrow and emergency spillway areas of all sites in Group II-a and all sites in II-b, and II-c with maximum height of dam 25 feet or over.

Representative undisturbed samples are seldom required for shear tests of foundation materials of dams under 25 feet in height in Group II sites. Normally undisturbed samples for shear tests are not required in Group II sites for structures between 25 and 35 feet unless highly questionable materials of low shear strength are encountered. This would include soft clays and silts which, due to the nature of particles, develop low shear resistance.

Samples for consolidation tests are required for the same conditions as those outlined for shear tests above as well as for depths greater than the equivalent height of the dam if compressible materials are encountered.

Requirements of samples for permeability, water testing, soil-cement testing, and reservoir sealing in this group are the same as for those in Group I dam sites.

#### Group III Dam Sites.

Sampling of dam sites for Group III structures normally is not necessary if adequate information and experience is available in the area on which to base conclusions. Where such information is not available, or, where highly questionable conditions are encountered, sampling may be necessary. Normally few undisturbed samples are required for sites in this group.

#### Other.

Water.---Samples of groundwater, intended for laboratory analysis, must be uncontaminated by foreign substances. The quantity of water required for a chemical analysis varies with the laboratory technique. A common requirement is one liter or quart, but some laboratory techniques require up to one gallon. Therefore, unless the requirements of the laboratory in which the water is to be analyzed are definitely known, it is advisable to take a one-gallon sample, which should be preserved in a thoroughly cleaned glass container, adequately sealed and packed for shipment.

Soil cement.---Samples are usually representative or composite selections of materials available and are therefore disturbed. Very large samples (75 to 100 pounds) are required to test for soil-cement or other soil stabilization measures.

Since the number of tests for these measures may vary among different laboratories, the particular testing agency involved would be contacted and their requirements for quantity ascertained.

## CHAPTER 4. EQUIPMENT AND EXPLORATION METHODS FOR GEOLOGIC INVESTIGATION

### General

Geologic exploration and sampling for soil mechanics testing requires special equipment and tools. Guidelines for determination of justification for purchase or rental of drilling equipment and procedures for procuring, financing, staffing, and scheduling drilling equipment are contained in Engineering Memorandum SCS-36.

There are many types of equipment and tools on the market designed for specific types of work. The type of equipment and tools needed to make geologic exploration for a specific site depends upon the type and depth of materials encountered, the intensity of investigation needed, need for undisturbed samples, etc. Hand tools may be adequate for exploration work for certain types of structures in Group III. Power equipment such as backhoes and dozers may be adequate for exploration of certain types of structures for Group I sites. This chapter outlines briefly the various methods of subsurface exploration applicable to Service work and describes types of cutting and sampling tools and other equipment needed to conduct geologic investigations of dam sites.

### Exposed Profiles

#### Natural Exposures.

A complete investigation of formations in natural exposures at the surface is necessary to provide a basis for subsurface investigations and to eliminate unnecessary drilling. Natural exposures and materials exposed by power equipment or other equipment (trenches and test pits) are to be described in some detail. The description will serve the same purpose as other logs in establishing geologic conditions and obtaining information for design and construction. A fresh surface is required for preparation of adequate descriptions. An ordinary hand shovel or geologist's pick may be required for preparing the surface of a natural exposure.

#### Trenching and Test Pitting.

If bedrock is anticipated at a shallow depth trenches and test pits should be located on the centerlines of the structure and dug parallel with it.

If bedrock is not at shallow depths deep trenches or test pits should be offset from the centerlines to avoid damaging the foundation of the structure. Shallow trenches or test pits may be dug adjacent to the centerlines for correlation purposes. Topsoil or organic soil should be stripped and stockpiled separately from the mineral soil to prevent contamination of foundation or borrow material when backfilling.

In cases where pits or trenches penetrate and/or pass through materials which will constitute the foundation, it is requisite that backfilling be performed in such a manner as to obtain soil densities (compaction)

at least equal to the density of the original, in-place material. It is recognized that certain limitations exist to the use of trenching and test pit excavating equipment for compacting fill material. However, every practical effort should be made to re-establish the in-place densities of foundation materials.

**Trenching.**--Trenching is a simple method of shallow exploration of easily excavated rock or soil which permits visual inspection of strata. This is of great value in logging profiles and selection of samples. Type of material and ground water usually limit this method to depths of 10 to 15 feet. Trenches are advantageous in studying the various formations on steep slopes and in exposed faces. Trenches made by power equipment, such as backhoes and bulldozers, may require hand trimming of the sides and bottom to reach relatively undisturbed material.

This method is of particular value in delineating the rock surface beneath the principal spillway and in exploring emergency spillway materials. In the emergency spillway the contractor can see the formations to be excavated and can make a more accurate determination of the type of equipment required and the hazards to be considered in estimating costs. In materials containing many cobbles or boulders, where drilling is difficult, trenching may be a more feasible method of investigation. On the center-line of the dam, trenches may yield valuable information on rock excavation and core trench depth, especially where thin-bedded or flaggy rocks are found near the surface.

**Test Pits.**--Test pits are rectangular or circular and large enough to admit a man and his sampling equipment. They are excavated by hand or by the use of a clamshell or orange-peel bucket. However, power equipment should be used only for rough excavation and with extreme caution when approaching the depths at which undisturbed samples are to be taken.

Cribbing is required in unstable ground and for any deep pits. Since deep test pits will seldom be used for Service work, detailed discussion of methods of cribbing will not be undertaken here. This subject is adequately covered in the references.

The advantages of test pitting are about the same as for trenching and have the added advantage of being adaptable to greater depths. Disadvantages include time loss and cost where cribbing is necessary. With adequate dewatering equipment they can be extended below the water table and with cribbing they can penetrate unstable materials.

### Bore Holes

#### General.

Bore holes represent the most common method of making subsurface investigations. Various types of drilling equipment and tools are available for advancing bore holes, for sampling materials and for conducting other types of operations. Only the more common methods of boring applicable to Service work are described in this section.

### Hand Auger Borings.

Hand augers are useful for logging and sampling shallow borings (usually less than 10 feet), for exploration of very low dams and for preliminary site investigations of larger dams. Under some conditions, as in very wet areas which are inaccessible to drilling rigs, hand augering may be the only practical means of exploration. Usually a 3-inch diameter bucket-type hand auger (Iwan) is found to be most useful. This method cannot be used where undisturbed samples are required.

Several kinds of motorized hand augers (post-hole augers) are available on the market. Although a shallow hole can be advanced rapidly, their limitations in respect to Service work are similar to those of hand augers.

### Power Auger Borings.

Power augers mounted on trucks or jeeps are used for fast boring in unconsolidated materials. A small amount of water may be required in the hole to make the material adhere to the auger bit if it is dry and loose. The soil removed by the auger, although highly disturbed, is generally suitable for identification and laboratory tests requiring only disturbed samples such as those taken in borrow area investigations. Because of its speed, power augering is recommended where applicable, for geologic dam site investigations by the Service, in conjunction with rotary drilling (see figure 4-1).

### Wash Borings.

A wash boring is a means of advancing a hole by a striking or rotating action of a cutting tool and by jetting with water which is pumped through the hollow drill rod and bit. Cuttings are removed from the hole by the circulating water. The method is not recommended for Service use where identification of materials is necessary because of the sorting processes which take place in the transport of materials. Wash boring may be used for rapid advancement of a hole to determine depth to rock or to a given elevation in non-coherent materials to obtain a sample by other methods, and for setting piezometers.

### Drive Borings.

This method consists of forcing a tube into soil materials and retrieving a sample which is retained in the inside of the tube. Drive samples provide for identification of certain types of materials such as soft clays and silts and other materials free from gravel, cobbles and boulders. Although excellent for logging purposes, continuous drive boring represents a slow method of advancing holes. Undisturbed samples may be obtained from certain types of material, in which case this method is recommended (see Chapter 5).

### Rotary Drilling.

In rotary drilling, the bore hole is advanced by rapid rotation of the drilling bit which cuts, chips, and grinds the material at the bottom of the hole into small particles. The cuttings are removed by pumping water or drilling fluid from a sump down through the drill rods and bit and up through the hole, from which it flows into a settling pit and back to the sump.



Figure 4-1 Power Auger

Compressed air is used on many newer rigs to remove the cuttings from the hole. However, this is not very satisfactory in wet formations which are frequently encountered in dam site investigations. A reverse water circulation is employed on rigs used to drill large diameter holes such as water wells. In this case the drilling fluid passes down through the hole and up through the drill rods. The higher upward velocity of the fluid through the drill rods facilitates removal of cuttings from such large holes. This method has little use for Service subsurface exploration.

The power unit, rotary driving mechanism, winches, pump, folding mast, and in some cases a water tank, are assembled as a unit and mounted on a truck or trailer (see figures 4-2 and 4-3). Power for the drill head and pump may be supplied either by power take-off from the truck or by a separate power unit, although the latter is usually preferable. Rotary drilling may be the only practical method of obtaining undisturbed core samples of certain soils and rock materials. Because of the necessity of obtaining accurate identification of materials and reliable undisturbed samples for soil mechanics testing, the more versatile rotary core drilling equipment is recommended for Service work. With this equipment any of the above methods of advancing holes can be used.

### Geophysical

Geophysical methods may be used to supplement test holes but cannot replace them. It is necessary to drill a limited number of test holes to accurately interpret the results given by geophysical procedures. Geophysical methods are rapid and economical and may reduce the number of test holes that are required at a particular site to establish geologic continuity. With test hole control, geophysical methods may be helpful in delineating the bedrock profile and determining the continuity of strata between borings.

### Seismic.

The seismic refraction method is based on the variable rate of transmission of seismic or shock waves through the different materials composing the earth's crust. Several types of operating procedures have been developed. In one method, small explosive charges are set off in shallow holes. The seismic wave so generated is picked up and its time of arrival is recorded at several surface detecting points. The travel time of the wave to these recording points is measured and the wave velocity of different strata may be calculated. From these data the depths and probable character of various beds or layers can be inferred. See Figure 4-4 for schematic drawing.

Light-weight portable refraction seismographs have been developed which accurately measure the time interval for travel of a sound wave from a source to the instrument. In this method the shock wave is created by a sledge hammer blow on the ground and is picked up by a geophone. The mechanical energy of the wave is transformed by the geophone into an electrical signal which in turn is fed into the receiver. The time interval of the seismic wave is recorded and read directly on the instrument by means of binary counters.



Figure 4-2 Rotary Drilling Rig

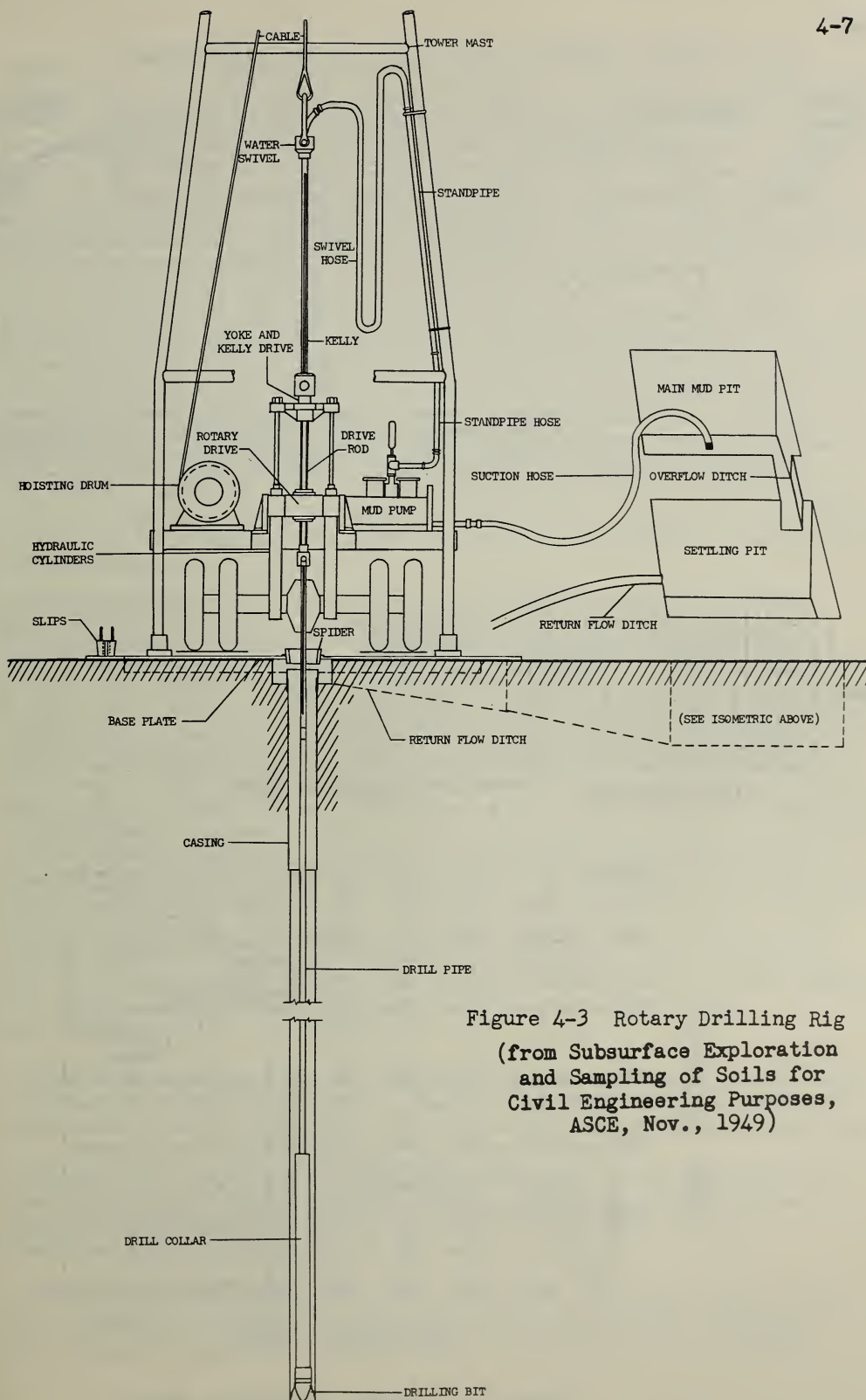


Figure 4-3 Rotary Drilling Rig  
(from Subsurface Exploration  
and Sampling of Soils for  
Civil Engineering Purposes,  
ASCE, Nov., 1949)

4-8

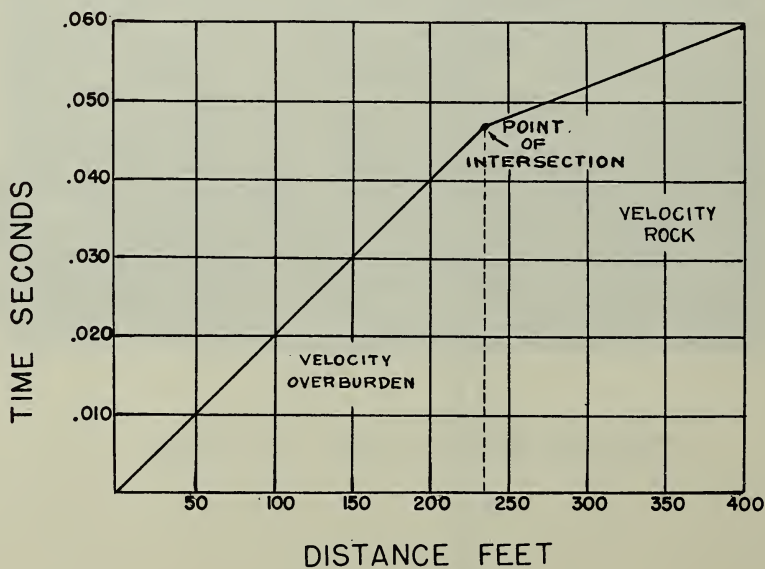
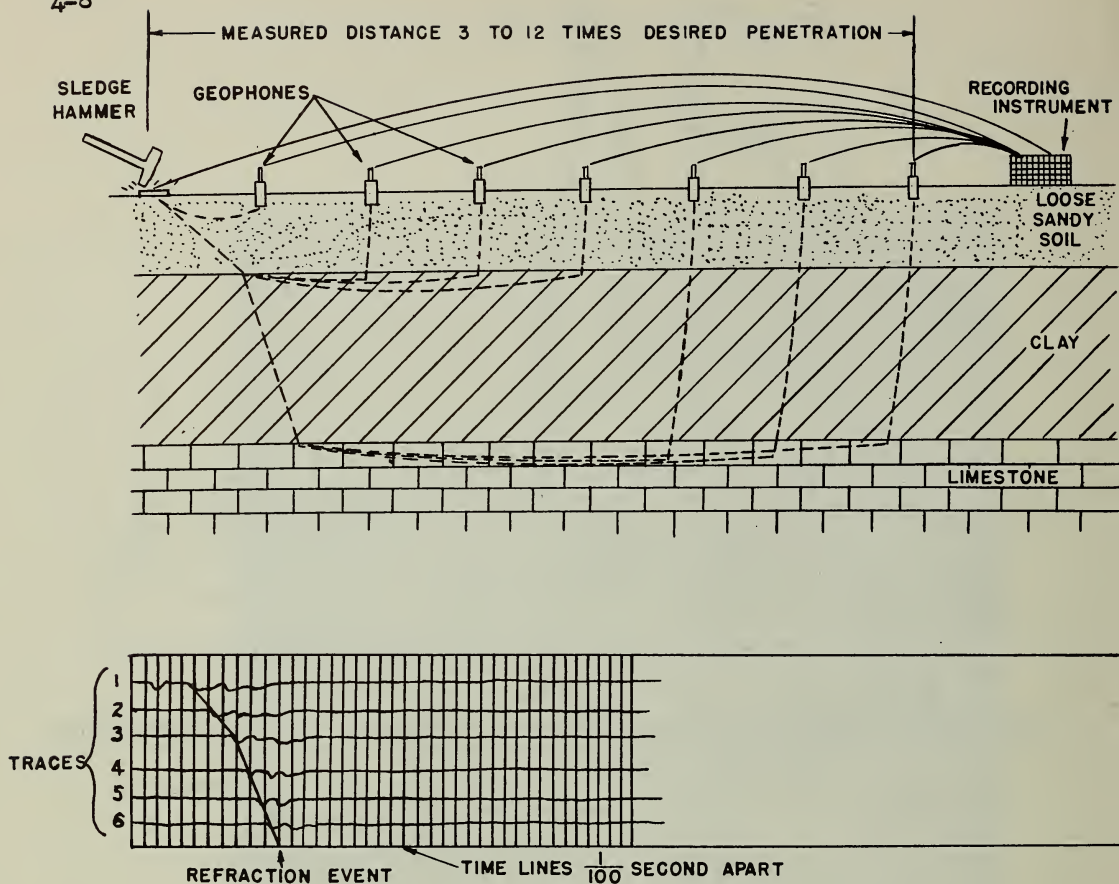


Figure 4-4 Seismic Refraction Method

Operation of this equipment consists of striking the ground with a sledge hammer at various distances from the receiver. A switch on the hammer is connected by cable to the instrument. The hammer blow triggers the binary circuit which continues to count until the first sound wave travelling through the ground is received. The velocity of the wave is then computed in respect to the registered time and the distance of the hammer from the instrument. Changes in the physical characteristics of underlying materials are indicated by the changes in velocities (distance/time) recorded by the instrument.

This instrument is limited to depths of about 50 feet and to rather simple problems of geology. For example: (1) A single discontinuity between two formations, (2) dipping discontinuity, and (3) two horizontal discontinuities, providing each formation becomes progressively denser with depth. Because the velocity of sound in water is about 5,000 fps., ground-water tables can be delineated in formations having seismic velocities less than that of water. The equipment is relatively inexpensive compared to seismographs used for oil and mineral exploration work. Although used only to a limited extent in Service work to date, it appears to have possibilities for reducing the number of test holes needed for geologic site investigations.

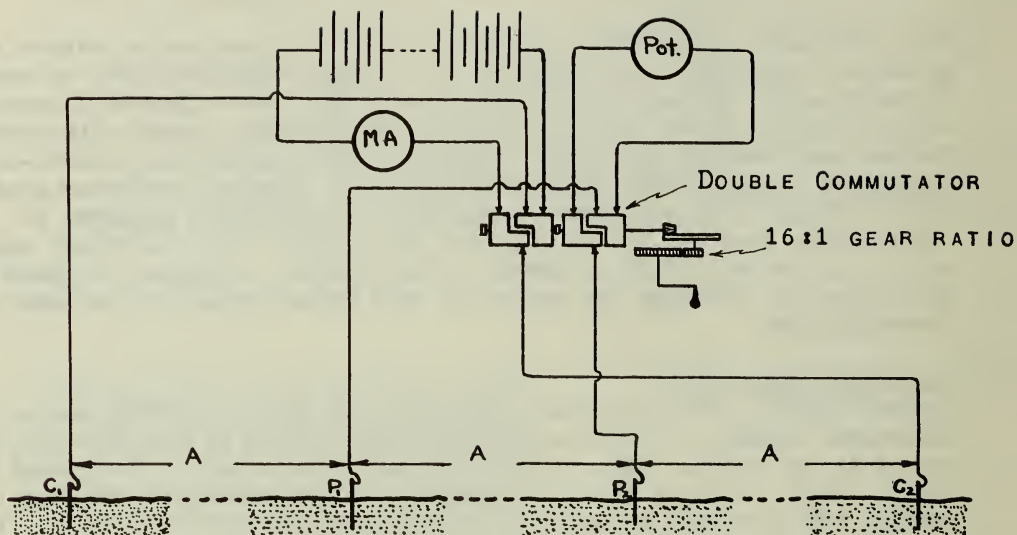
#### Electrical Resistivity.

The resistivity, or electrical resistance, of earth materials can be determined readily by causing an electrical current to flow through the ground to be tested. Usually, four electrodes are set in the ground in a line and at an equal distance apart. A set of batteries and a milliammeter are connected in series with the outer pair of electrodes. These are the two current electrodes. A potentiometer for measuring voltage is connected with the inner pair of electrodes. They are the potential electrodes. In many types of instruments a device, such as a commutator, is incorporated in the circuit for the purpose of reversing the polarity of the current electrodes. This procedure permits the registering of several potential readings for comparison. By measuring the current and the potential drop between the two inner potential electrodes, the apparent resistivity of the soil to a depth approximately equal to the spacing interval of the electrodes can be computed. The resistivity unit is often designed so that the apparent resistivity is read directly on a potentiometer using the principle of a wheatstone bridge (see figure 4-5).

In sediments or loose rock the resistivity meter will show a marked drop in potential at the water table. However, in solid rock the greater resistance of the material will often mask the presence of the water table.

In "resistivity mapping" or "traverse profiling", the electrodes are moved from place to place without changing their spacing. The resistivity and any anomalies to a depth equal to the spacing of the electrodes can be determined for the various points.

In "resistivity sounding" or "depth profiling" the center point of the setup remains fixed while the spacing of the electrodes is changed. By plotting the apparent resistivity as a function of the electrode



Legend.

MA - Milliammeter  
Pot.- Potentiometer

C<sub>1</sub>, C<sub>2</sub> - Current electrodes  
P<sub>1</sub>, P<sub>2</sub> - Potential electrodes

A - Uniform spacing between electrodes

Figure 4-5 Diagram of Resistivity Apparatus

spacing, the subsurface conditions may be indicated. A break or change in curvature of the plotting will generally be noted when the electrode spacing equals the depth to a deposit with a resistivity differing from that of the overlying strata.

The electrical resistivity method and refraction seismographs have been used complementing each other with good results, particularly in delineating gravel lenses, bedrock and the ground-water table. However, salt water and saline soils have a marked influence on conductivity. Although the resistivity method is not being used at the present time for Service work, it has promise as an economical supplement to drilling for establishing geologic continuity at specific sites.

### Penetration

#### Standard Penetration Test.

Penetration resistance tests consist of forcing a rod, pipe or sampling tube into a soil and measuring the resistance to penetration. This is a quick and inexpensive method of roughly determining the in-place condition and stability properties of subsurface soils. Changes in the rate of penetration indicate a change of material or of in-place conditions.

This test is particularly applicable to non-cohesive materials. Penetration resistance of cohesive material is influenced by moisture content and the results of tests conducted in such materials are used to describe relative in-place conditions. Where standard penetration tests are made in cohesive materials, samples must be taken to determine in-place moisture conditions (see Chapter 9).

The equipment necessary to provide the driving force in the standard penetration test is a hoist-winch and a 140-pound hammer. The hammer is dropped an average of 30 inches (see figure 4-25). In the standard penetration test of Terzaghi and Peck the above equipment and length of fall is used to drive a standard sampling spoon of 2" outside diameter (1.375" I.D.). The penetration resistance is measured according to the number of blows required to drive the pipe one foot into the soil (see Table 9-4).

### Vane Shear

Vane shear tests are a method of determining the shearing resistance of a soil in-place by rotating a vane (see figure 4-6). The vane is pushed into the soil to be tested and rotated at a constant rate by means of a torque wrench or other calibrated torsion device. The moment or torque required to turn the vane indicates the shearing strength of the soil. This test is limited to soft cohesive soils and is not recommended for general Service use at the present time.

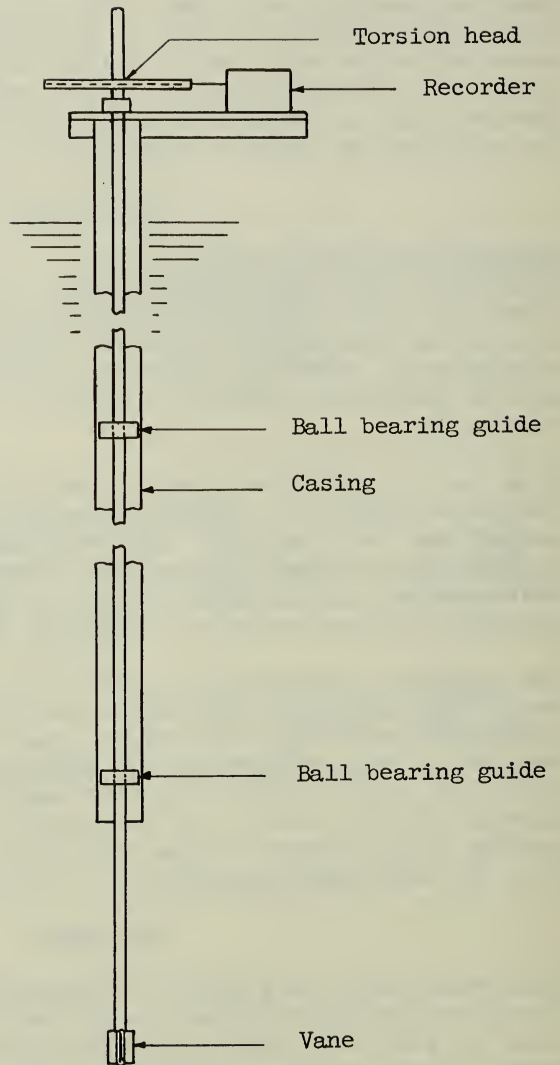


Figure 4-6 Idealized Vane Shear Apparatus

## Water Investigation

### Pressure Tests.

Water pumps having minimum capacities of 50 gpm at discharge pressures of 100 psi are needed. Double expander packers with rubber expansion elements set five (5) feet apart are used in the test. It is necessary to have available and to arrange water pipes so as to admit water below the bottom expansion element or between any two expansion elements. The water pipes are connected to the pressure pump through a pressure relief valve, a pressure gage and a water meter. Additional equipment includes accessory valves, gages, stopcocks, plugs, and tools necessary for maintaining uninterrupted tests.

Where pressure testing is required, the holes should, in general, be tested in five (5) foot intervals. The conditions encountered will indicate whether testing will proceed from top to bottom or vice versa. For each interval or lift, the maximum water pressure at the upper expander should not exceed one (1) pound per square inch per foot of depth. The testing device consists of a length of perforated pipe equipped with a rubber packing at each end. The pipe is secured in the hole by pumping water into the packers or mechanically locking the packers and effectively isolating the section between the packers. Water is then forced into the interval between the packers by the pressure pump (see figure 4-7). Ordinarily, the interval water pressure is 50 psi. A hole may be tested in its entire length by removing the plug from the bottom of the pipe. The pressure or holding test consists of raising the pressure in the interval to the initial test pressure (50 psi), closing the stopcocks and cutting off the pressure pump. Note is made of the time required for each 10 psi drop in pressure on the pressure gage. If the pressure drop does not exceed 10 psi per minute, it is evidence that there is no appreciable leakage in the particular interval; no pumping test is required in this case.

Field observations for flow tests and holding tests may be compiled on Standard Form SCS-        which is provided for this purpose (see figure 4-8). Interpretations of field data may be facilitated by use of graphic curves shown in figure 4-9.

### Pumping Tests.

The same equipment used in pressure testing may be employed in pumping tests. Where pressure tests indicate "leakage" of strata or of an interval at rates in excess of 10 psi per minute, pumping tests will be conducted. The tests require notations of the volume of water pumped into a "leak" as recorded by appropriate water flow meters. Pumping tests are run continuously until a constant or nearly constant maximum discharge rate is reached. This may require readjustments of initial pumping rates due to a build-up of water-depleted zones.

### Gravity Method.

An alternate method for the determination of water transmissibility involves the measurement of a constant head of water. In some cases the zone to be measured requires isolation from the rest of the hole lying below. This isolation can be accomplished by plugging or

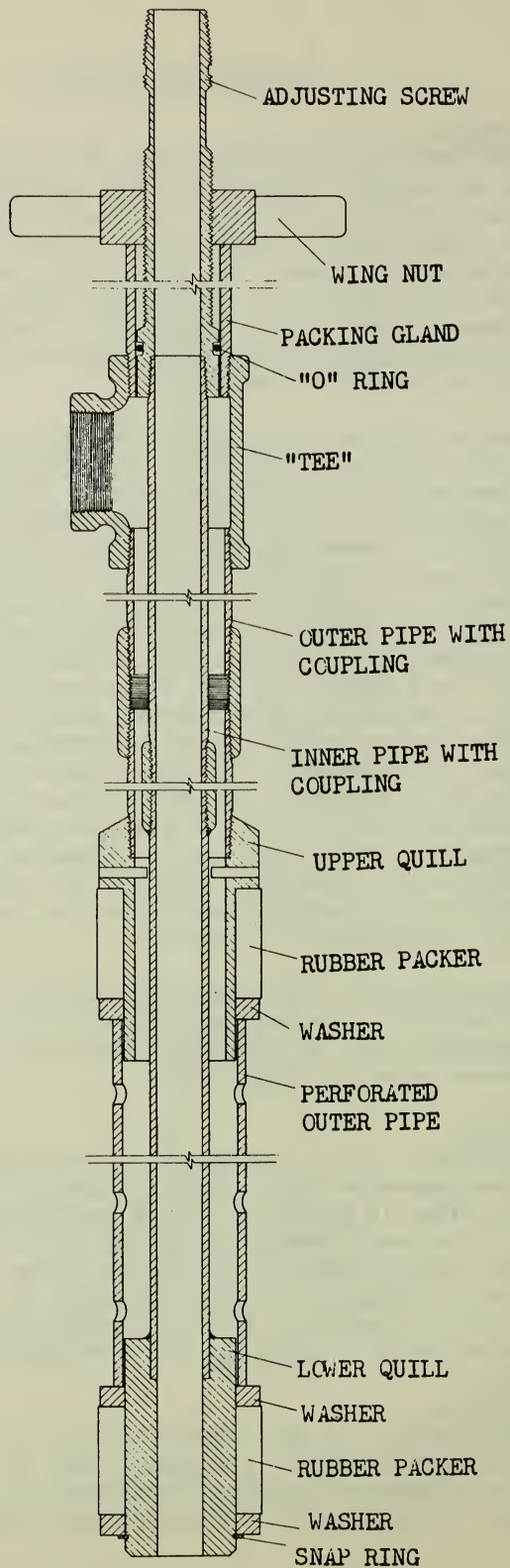


Figure 4-7 Pressure Testing Tool (Sprague and Henwood)

Dam Site \_\_\_\_\_, River \_\_\_\_\_, Hole No. \_\_\_\_\_, Rig No. \_\_\_\_\_

Location of Hole \_\_\_\_\_

Contractor	Driller	Elev. top of hole
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Type of Pump	No. of Pump	No. of Meter
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## PART 1 DATA ON FLOW TEST

[illegible]

PART II

HOLDING TEST - MAXIMUM PRESSURE 50 p.s.i.

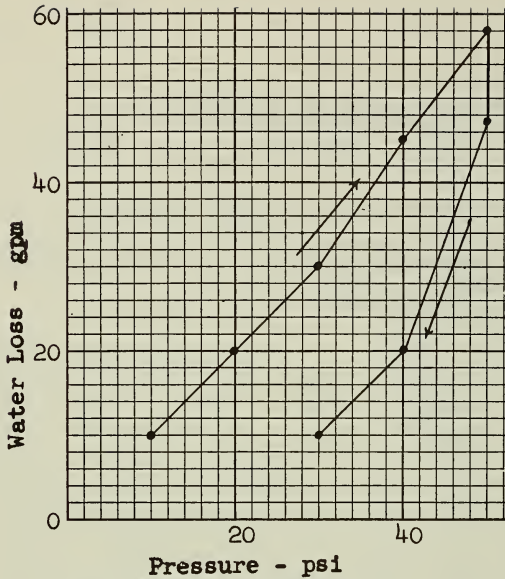
[illegible]

Description of operations and general information:

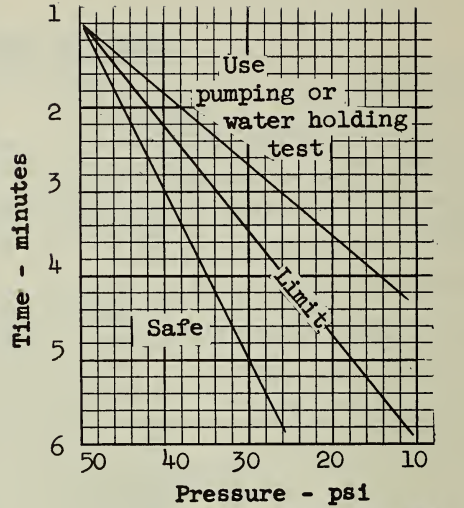
Elev. ground  
Elev. Top Rock  
Bottom Hole

Inspector's Signature

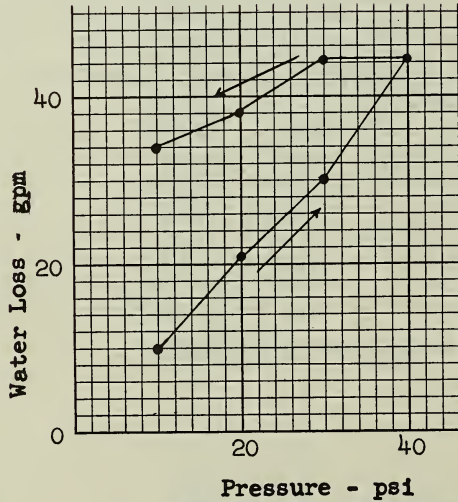
Figure 4-8 Pressure Testing Data Sheet



a. Fissures opened by increased pressure -- leakage problem



b. Pressure-holding test



c. Self-sealing formation -- no leakage problem.

Figure 4-9. Sample Plots of Pressure-test Data

grouting the portion of the hole not being measured. The hole is filled with water and the level of water maintained at a fixed elevation by continuous pumping. The volume of water needed to maintain a constant head is recorded from a flow meter attached to the pump and rates of flow are noted for regular time intervals. After initial surging has ceased, continuous readings should be taken until a constant rate of inflow has been established.

### Types of Cutting and Sampling Tools

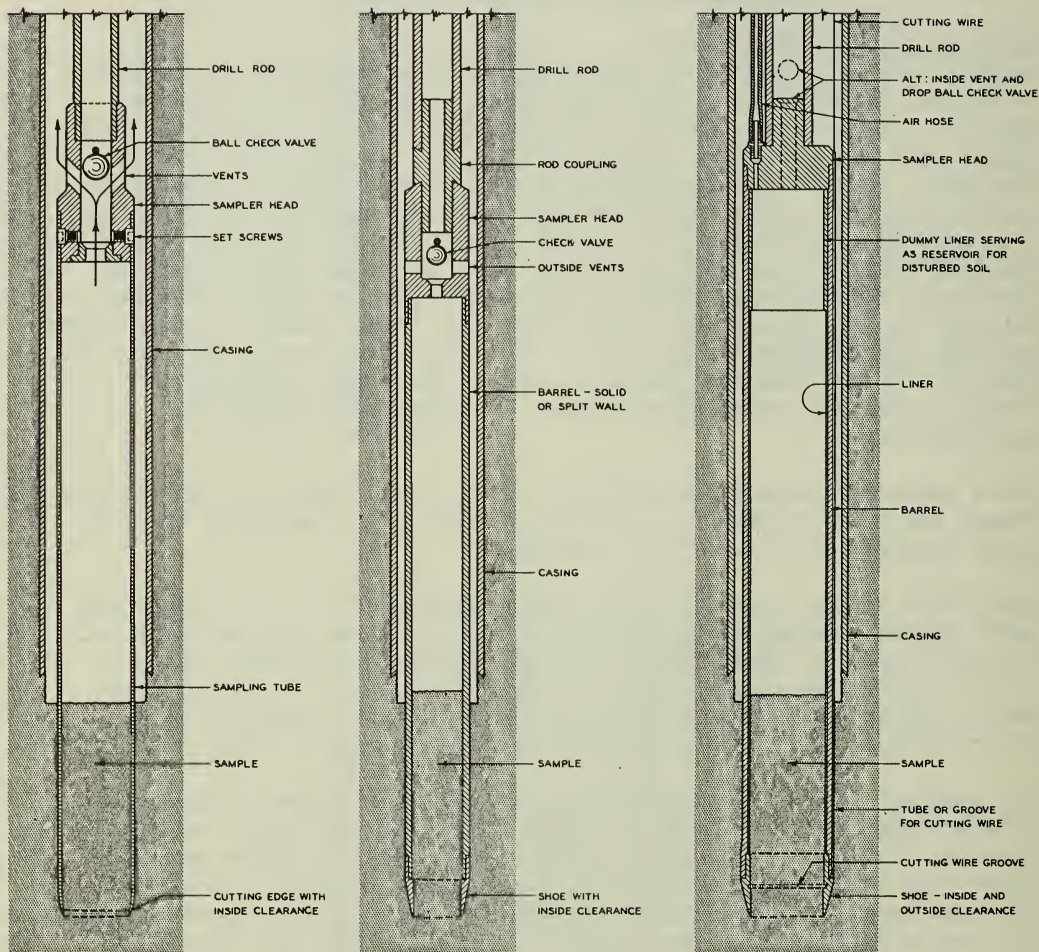
#### Drive and Push-tube Samplers.

General.--A large number of these samplers are available on the market, including the split-tube, cup, split barrel, piston, and push-tube samplers. These are known by various names, such as the Porter, Mohr, Piggot, M.I.T., Vicksburg, Moran and Proctor, Langer, and St. Paul samplers. These samplers are forced into unconsolidated material by various methods, including hammering, jacking, pushing, and shooting with explosives. In general, a uniform and uninterrupted push provides the least disturbance to the sample. Some of these samplers contain plastic or metal lining tubes, in which the samples may be left for shipment to the laboratory. In others, the sample must be removed from the tube for shipment or the tube itself containing the sample must be shipped. These samplers cannot be used effectively in gravel or cobble materials, cemented materials, or materials too hard for penetration.

Drive samplers are manufactured in a variety of diameters, tube thicknesses and tube lengths. In general, they may be classified as open drive samplers and piston type samplers.

Open drive samplers.--Open drive samplers consist of solid barrel and split barrel samplers. Open drive samplers must be equipped with ball or other types of check valves for satisfactory performance (figure 4-10). Split-tube samplers may be equipped with basket or flap type sample retainers. A split-tube sampler may also be obtained with a liner which may be removed, sealed and shipped to the laboratory.

The simplest type of open drive sampler is the so-called, thin-wall, "Shelby Tube", (figure 4-11). Designed primarily to secure samples of cohesive silts and soft clays, it may be obtained in either steel or brass tube boring lengths up to 30 inches and I.D. up to 5 inches. The tube is attached to a head assembly by means of set screws. After the sample is obtained, the tube is detached, sealed and shipped to the laboratory where it is cut into sections and the sample extruded, or otherwise removed, for tests. The sampler has a ball-check head which can be used with either BW or NW rod connection. The tube does not have a cutting shoe but has a sharpened cutting edge. To provide clearance in certain materials the edge is formed to cut a sample smaller than the inside diameter. Refer to table 5-1 for recommended bit clearances.



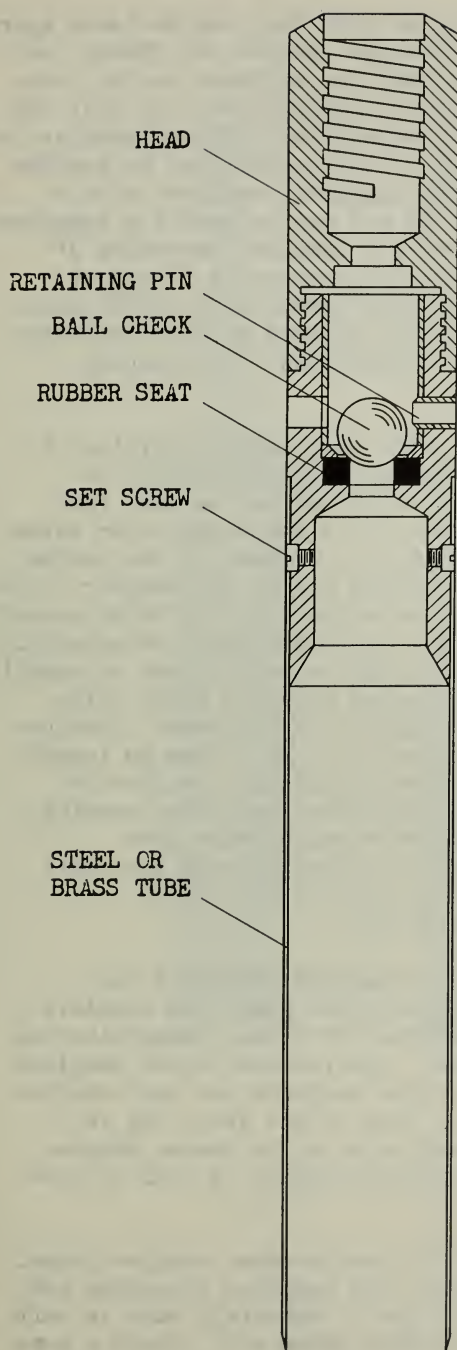
THIN-WALL OPEN DRIVE SAMPLER

THICK-WALL OPEN DRIVE SAMPLER

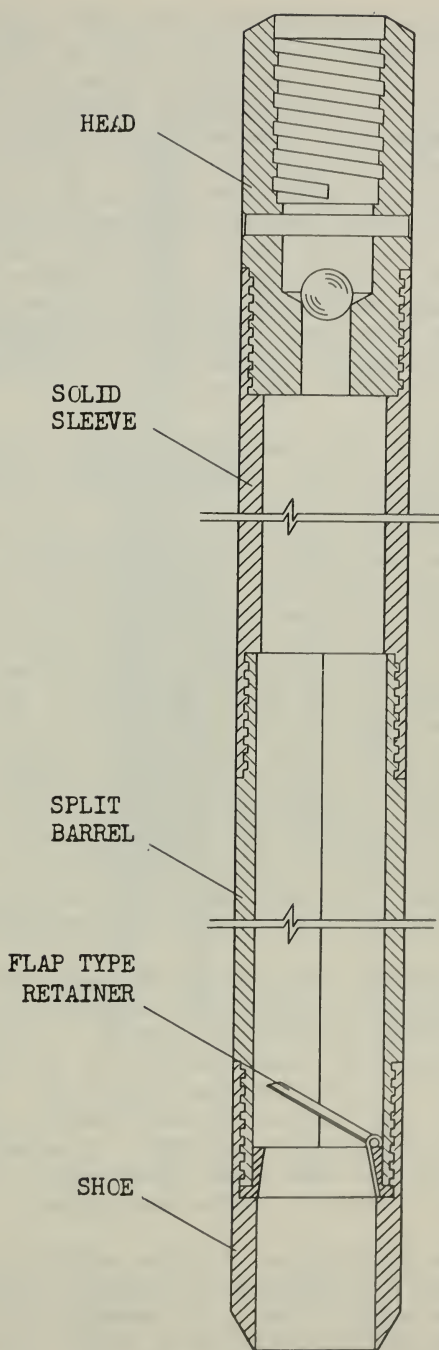
COMPOSITE OPEN DRIVE SAMPLER

(op. cit. p.4-7)

Figure 4-10 Drive Samplers



"Shelby" Type Sampler



Split Barrel Sampler

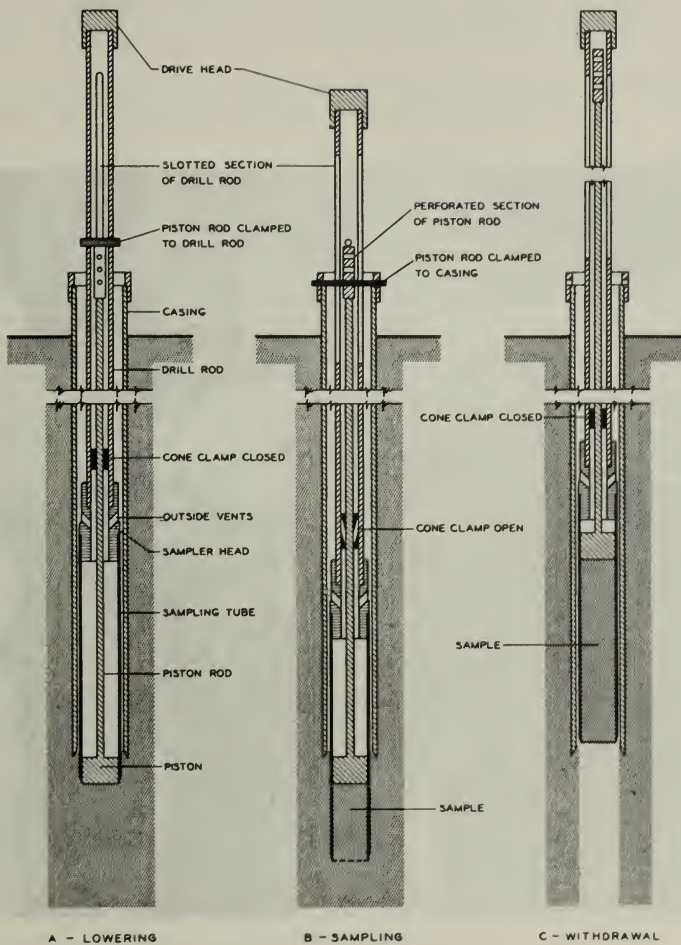
Figure 4-11 Split Barrel and "Shelby" Type Tube Samplers

Split-tube samplers are split longitudinally so that they can be taken apart by removal of the head and the shoe and the sample removed for visual inspection and packing in jars or other containers for shipment to the laboratory. Wall thickness is greater than that in "Shelby Tubes" so that the sampler will withstand hard driving into soil materials to obtain samples or conduct penetration tests. Split-tube samplers may be obtained in lengths up to 24 inches and I.D. up to 5 inches. The sampler is equipped with a ball check head and hardened cutting shoe. BW rod may be used for samplers of I.D. less than 3" while NW rod is required for samplers exceeding 3" I.D. Certain types of split-tube samplers contain removable liners of brass, steel and plastic. These are available in sizes up to 3-7/8" I.D. The liner with sample may be removed, sealed and shipped to the laboratory for testing. These are not recommended for Service use for obtaining undisturbed samples.

Piston drive samplers.--Piston samplers are thin-wall samplers similar to "Shelby Tubes" but containing a piston to facilitate sampling. It is designed to obtain samples of soft or medium soils and may be used for obtaining samples of sands, silts and cohesive soils below the water table. The stationary piston type sampler (figure 4-12) is lowered to the bottom of the bore hole with the piston held in the lower end of the sampler. The piston is then locked into position by means of actuating rods which extend to the surface within the drill rods and the tube forced into the materials to obtain the sample. The sampler is equipped with a vented head to permit escape of air above the piston. The piston creates a vacuum which holds the sample in the tube while it is being brought to the surface. Stationary piston type samplers are available in sizes up to 30 inches in length with I.D. up to 4-3/8". The larger sizes, about 2-7/8" I.D. require NW rods. A modification of the above sampler (Osterberg) requires lowering of the sampler in the bore hole and forcing the sampling tube into materials by means of hydraulic water pressure applied through the drill rods. This type of sampler is available in the 3-inch and 5-inch diameters, the larger size requiring use of NW rod.

Appraisal of drive or of push-tube samplers.--Designed primarily for sampling cohesive silt and soft clay, the thin-walled push-tube samplers provide an excellent method of obtaining samples for visual inspection and laboratory classification of these materials. Heavy-walled drive samplers can be used in harder materials. The split-tube samplers are best adapted for this purpose although solid tubes may be used if the drill rig is equipped with a hydraulic or mechanical sample ejector to remove samples from the tubes (see figure 4-13). The split-tube sampler is used to conduct standard penetration tests.

The limitations of drive sampling for obtaining undisturbed samples depend upon the character of materials being sampled, the sampling procedure and the sampler used. For example, in certain types of materials such as soft and wet clays and silts large diameter, thin-wall tubes will obtain a more nearly undisturbed sample than the double-tube core barrel which alters the structure of material by barrel whip. The question of economics is also involved in use of thin-wall samplers. The extrusion of samples from solid barrel tubes, particularly swelled samples, may create disturbances of the sample which make their use as an undisturbed sample questionable.



(op. cit. p.4-7)

Figure 4-12 Stationary Piston Sampler

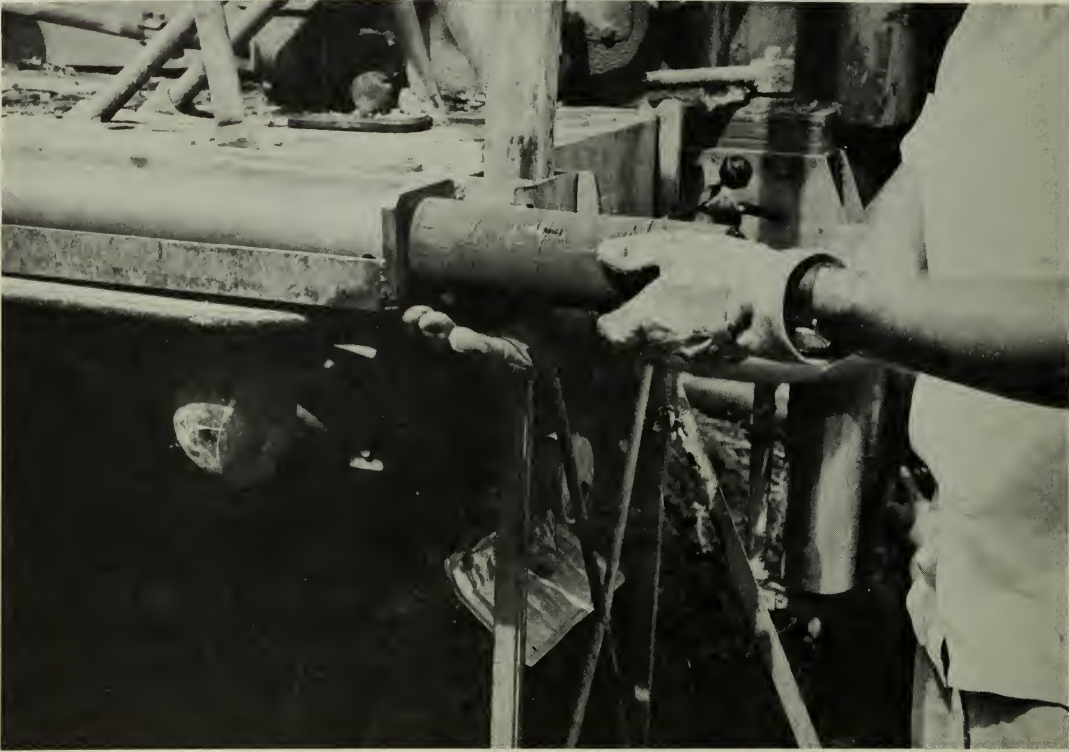


Figure 4-13 Hydraulic Sample Ejector

To eliminate this the tubes must be sawed or split in the laboratory which renders them unfit for further use. The cost of tubes per dam site, of course, varies with the number of samples obtained. However, this may be less costly than incorporating a higher safety factor in design because of inadequate undisturbed samples. Tubes equipped with cutting shoes should never be used to obtain undisturbed samples.

Tables 4-1 and 4-2 present guides to the selection of samplers for different types of materials and sample requirements.

Table 4-1

## Soil Types and Sampling Tools

Type of Soil	Logging or Disturbed Samples	Undisturbed Samples
Common Cohesive and plastic soils.	Bucket-type augers, all types of drive samplers.	Thin-wall open-drive sampler. Piston sampler. Double-tube core barrel.
Slightly cohesive and brittle soils including silt, loose sand above the water table.	Same as above.	Thin-wall open-drive samplers. Piston samplers below water table. Double-tube core barrel (with core).
Very soft and sticky soils.	Closed bucket auger. Piston sampler or open drive with core retainers.	Thin-wall or lined piston samplers.
Saturated silt and loose sand	As above. Overdrive push-tubes to retain sample.	Piston sampler with heavy mud.
Compact or stiff and brittle soils including dense sands, partially dried soils	Bucket-type auger. Thick-wall drive sampler.	Double-tube core barrel.
Hard, highly compacted or partially cemented soils, no gravel or cobbles.	Bucket auger. Thick-wall drive sampler and hammer. Double-tube core barrel.	Double-tube core barrel.
Coarse, gravelly and stoney soils including compact and coarse till.	Bucket auger <sup>1/</sup>	Not practical (Advance freezing and core).
Organic clay, silt or sand.	As above according to basic soil type	Thin-wall piston. Measure length of drive and original volume of sample carefully.

<sup>1/</sup> Power equipment such as bulldozers, backhoes, etc., are more suitable in many cases.

Table 4-2  
Samplers, Sample Sizes and Materials

Sampler	Minimum Inside (inches) Diameter Required For:				Materials in Which Used
	Logging only	Consolidation Tests $\frac{2}{2}$	Direct Shear	Triaxial Shear	Horizontal Permeability
Helical Augers	N.R. $\frac{1}{1}$	--	--	--	--
Ivan Augers	2	--	--	--	--
Bucket Augers	3-1/2	--	--	--	--
Slat-type Bucket Augers	3-1/2	--	--	--	--
Thick-wall solid tube	2	N.R.	N.R.	N.R.	N.R.
Thick-wall split tube	1-3/8	--	--	--	--
Split-tube with liner	--	3	3	5	5
Thin wall	2	3	3	5	5
Stationary Piston-Thin wall	2	3	3	5	5
Double Tube Core Barrel (Denison)	2-15/16	2-15/16	2-15/16	5-7/8	5-7/8
Double-Tube Rock Core Barrel	2-1/8	--	--	--	5
Single-Tube Rock Core Barrel	2-1/2	--	--	--	5

$\frac{1}{1}$  N.R. - Not Recommended.

$\frac{2}{2}$  Includes vertical permeability tests.

### Auger Bits.

Augering is one of the best methods of obtaining continuous disturbed samples in Service geologic investigations. Many types of auger bits are available on the market.

The helical or worm-type auger bit, sometimes called the flight auger, is the most common. These are usually made in sections which may be added just as drill pipe is added. The augered material is brought to the surface by the helical action of the auger. The obvious disadvantage of this type of bit is that material is mixed throughout the hole. It is difficult to obtain a sample representative of one horizon only unless a single flight is used and retracted when filled. Where it is necessary to obtain such a sample, augering should be stopped and a split-tube sampler substituted.

Other types, which have open sides, are known as the Iwan, spoon, and Vicksburg hinged augers. These are usually used only with hand-operated augers, but have the advantage of less mixing of material.

The disc auger is similar to the helical auger, except that it consists only of the bottom helix and has a shutter plate to retain the material. It is particularly adapted to drilling large holes, 24 to 60 inches in diameter. When used with a powerful machine, the material can be spun off the bit at high speed.

The Service has developed a set of auger bits, termed bucket auger bits, which are especially adapted to mobile power augers for Service geologic investigations. These bits are shown in figures 4-14 and 4-15. The open slat-type is adapted for use in cohesive materials, the closed cylindrical type in non-cohesive materials, and the semi-closed cylindrical type in intermediate materials. These bits are not available "off the shelf" from any manufacturer, and must be made up specially. They will obtain a representative sample from any horizon desired.

An outside diameter of about 6-1/2 inches is recommended as best suited to Service needs for initial augering when undisturbed samples of 5 inches are required. A set of these bits measuring 4-1/2 inches outside diameter is also desirable for use following a 5-1/2 inch core barrel or roller bit and preliminary to obtaining undisturbed samples of minimum 3-inch diameter. This type of bit may be used with either a rotary drilling rig or power auger. A different tool joint at the top of the auger bit, or a substitute, may be required for use on different rigs.

### Fish-tail Bits.

The fish-tail or bladed bit, which has several fins at the bottom, is used when it is desired to advance holes in unconsolidated material or soft rock without taking samples. The cutting surfaces of the fins are faced with tube borium or a similar hard alloy. Drilling fluid is pumped down through the center of the bit and carries the cuttings up through the hole. Two common types are shown in figure 4-16.

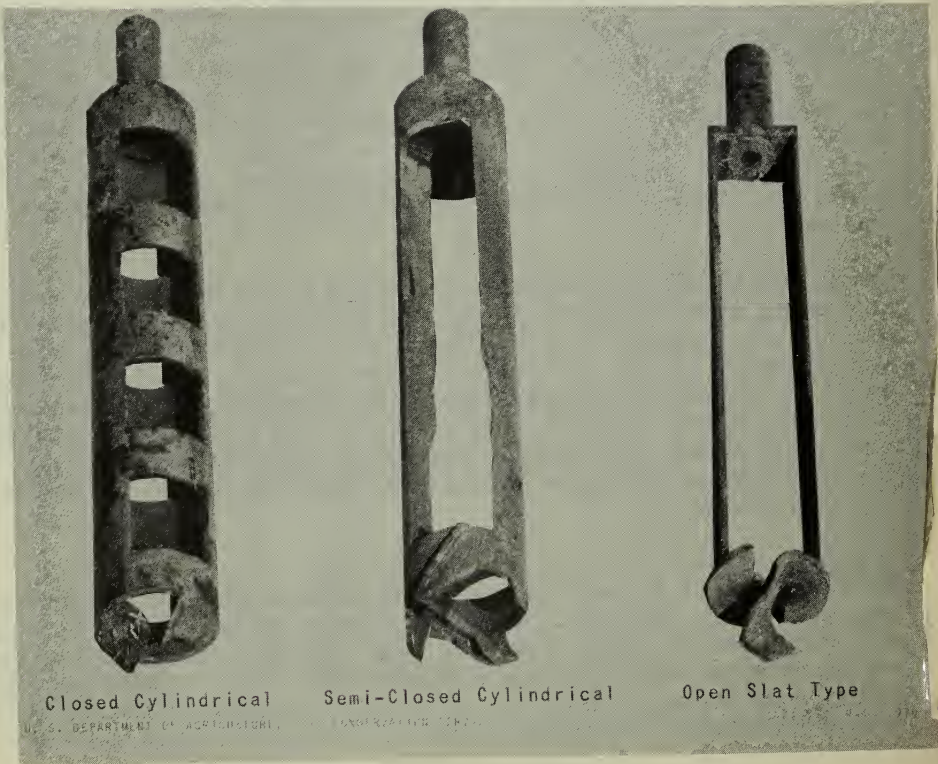
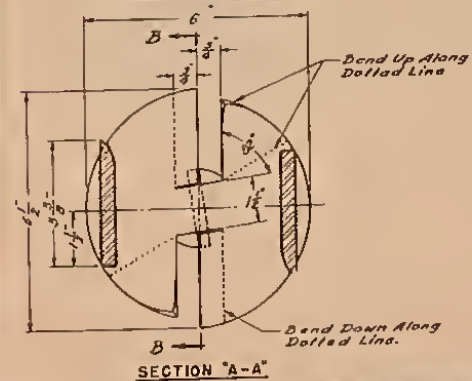
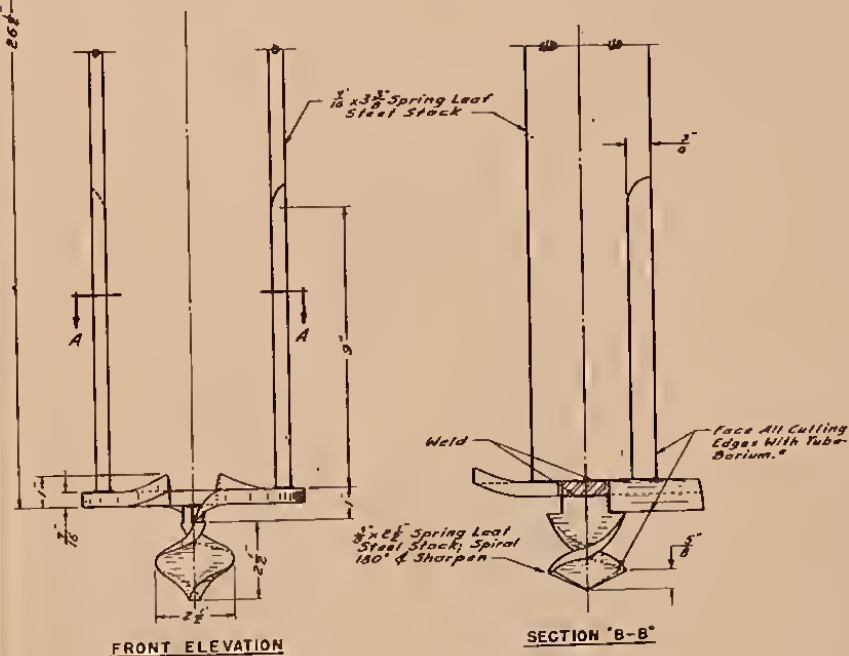
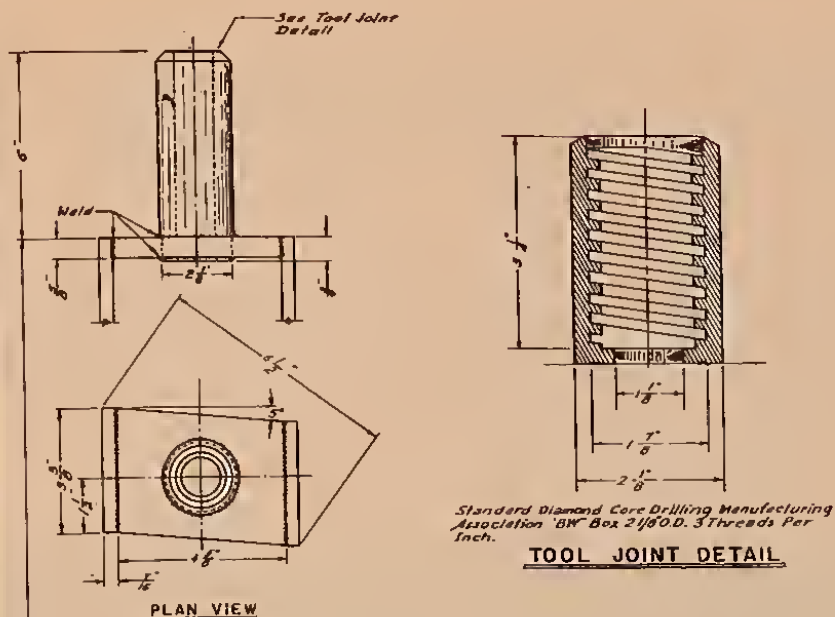
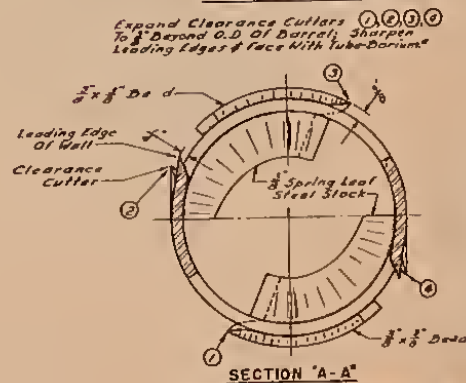
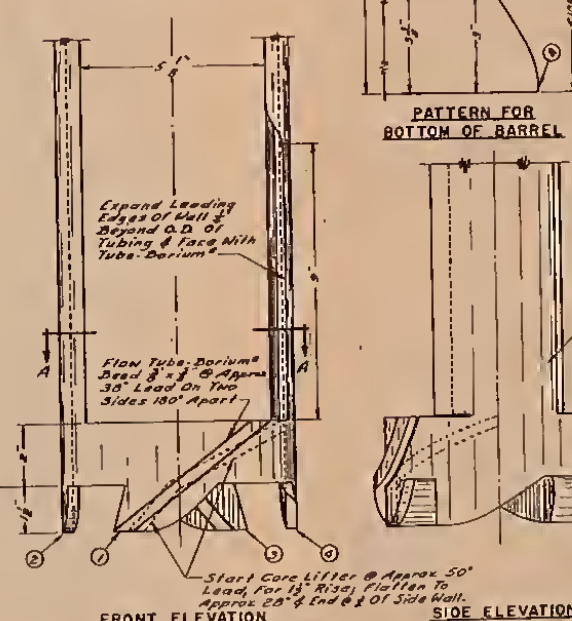
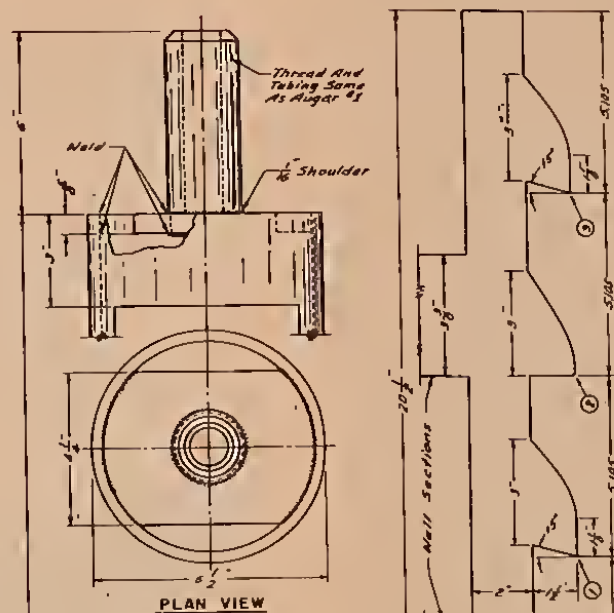


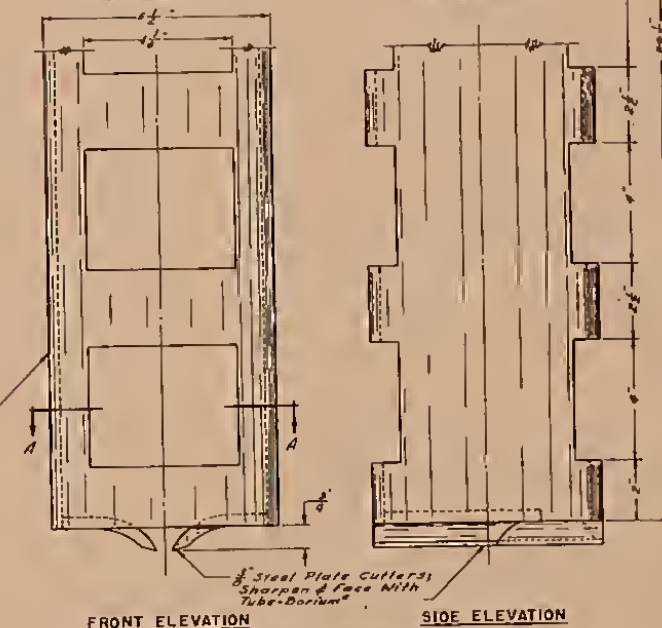
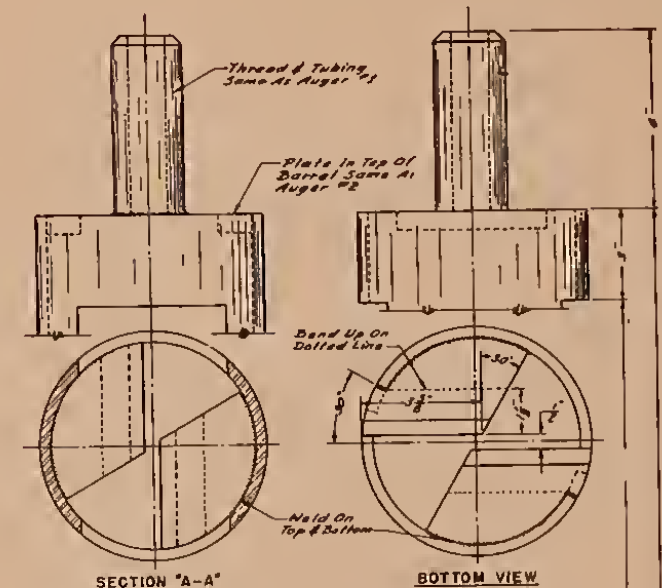
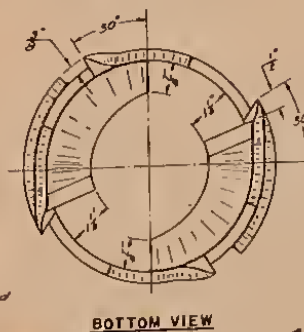
Figure 4-14 Various Types of Bucket Auger Bits



**AUGER NUMBER 1**



**AUGER NUMBER 2**



**AUGER NUMBER 3**

Auger Number 4 Shall Be Identical To Auger Number 3 Except That The Ring At Bottom Of Barrel Shall Be 3 1/2" High And Shall Have No Teeth Or Cutters. (To Be Used As Blank For Making Special Augers)

**AUGER NUMBER 4**

**GENERAL NOTES**

1. Flare Tube-Dorium® 30-40 On 3/8" Back From Both Sides Of All Leading Cutting Edges On All Augers.
2. Construct Augers Symmetrically About The & 30 That Cutters & Barrel Will Turn Concentric With Drill Rod.
3. Weld All Exposed Edges Of Welded Joints

\* Use "30-40 Tube-Dorium Or Equal.

**AUGER BITS  
FOR CORING MACHINE  
U.S. DEPARTMENT OF AGRICULTURE  
SOIL CONSERVATION SERVICE**

Figure 1-15 Auger  
Bits - section 1



Large fishtails, 20 inches in diameter, are sometimes used to make holes where Service drilling rigs are employed for relief well installation. The recommended size for normal Service exploratory work is 3 inches outside diameter. This size may be obtained "off the shelf", but larger sizes must be made up on special order.

#### Roller Bits.

Roller bits have several sets of rollers with inter-fitting, self-cleaning, hard-surfaced teeth. They are used for making holes in rock when no samples are required. The number of sets of rollers varies from two to four. The most common type is the tri-cone roller bit, with three sets of rollers. The teeth are flushed by drilling fluid flowing out of vents in



Figure 4-16 Various Types and Sizes of Fishtail and Roller Bits.

the base of the bit, and the cuttings are carried up through the hole. Three sizes of tri-cone roller bits are shown in figure 4-16.

In Service investigations, this type of bit is commonly used in conjunction with augering, to cut through rock without taking a sample, after which augering is continued with a slightly smaller bit.

Rock Core Barrels with Steel and Diamond Bits.

The core barrel obtains a sample of rock in the shape of a cylindrical core. The circular bit cuts the core and the barrel slides down over it. A ball-check valve to relieve water pressure and a core catcher assist in retaining the core in the barrel. Because a single-tube core barrel subjects soft rock cores to the erosive action of drilling fluid passing downward through the barrel, the double-tube core barrel is recommended for Service work (figure 4-17). In the double-tube core barrel, the inner tube does not rotate and the fluid passes between the inner and outer barrels eliminating its erosive action.

A double-tube NWX long core barrel, capable of taking a core of at least 2-1/8 inch diameter (3-inch outside diameter) (see figure 4-18) is recommended for Service use. In addition, a short barrel taking a one-foot core is needed to start the hole where rock outcrops at the surface and cores are desired from the surface down (figures 4-18 and 4-19). Core barrels smaller than NWX size are not recommended for Service work.

A split-ring core catcher is usually employed to seize the core when the barrel is lifted, breaking it off and holding it in the barrel. The core catcher may be attached to either the inner or outer barrel.

The inner barrel may or may not have vents. Omission of the vents theoretically reduces friction because water over the core must be forced out between the core and the inner barrel. On the other hand the fluid may cause erosion of soft rock cores if the vents are omitted.

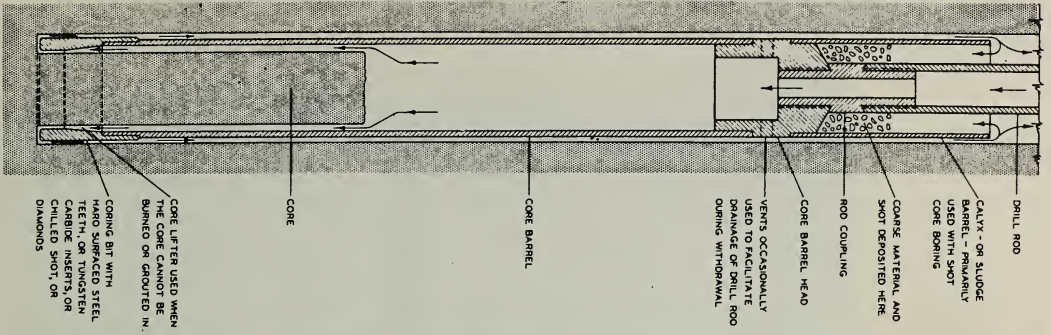
Core barrels may have either the "retracted inner barrel" or the "bottom discharge bit". In the retracted inner barrel the drilling water passes down between the inner and outer barrels, across the cutting teeth of the metal bit or the waterways of the diamond bit and up outside the outer barrel. It is used in non-erodible rock. In the bottom discharge bit the drilling fluid passes out through holes in the bottom of the bit proper, and thence up outside the outer barrel. It is used mainly in soft or broken rock.

The denison double-tube soil coring barrel can sometimes be used satisfactorily for coring soft rock. It is equipped with a metal toothed bit and basket-type core catcher of spring leaves instead of the split ring. The basket-type core catcher is rather delicate and is apt to break when used in rock. If the denison barrel is used for this purpose, care must be taken to use the long bit on the outer barrel, so as to prevent serious damage to the inner barrel shoe.

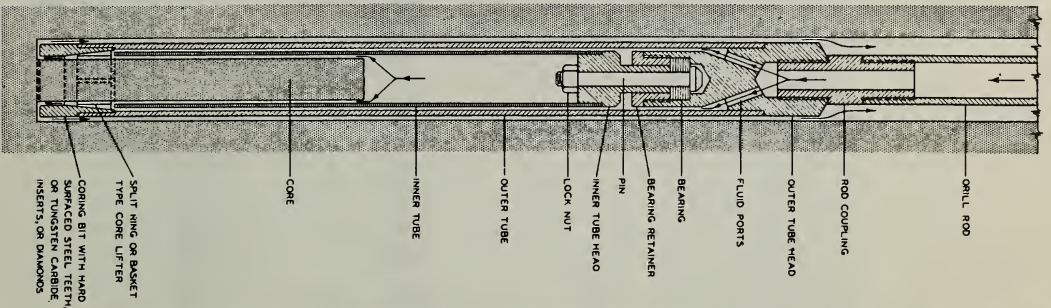
In general, a small number of relatively long metal teeth are preferable for coring soft formations, those containing clay streaks, or shales. On the other hand a large number of small teeth provides a greater rate of progress and causes less disturbance of the material when coring in medium-hard formations.

Steel saw-tooth coring bits are usually provided with teeth or inserts made of very hard and abrasive-resistant tungsten carbide alloys which are sold under various trade names such as Haystellite, Borium, or

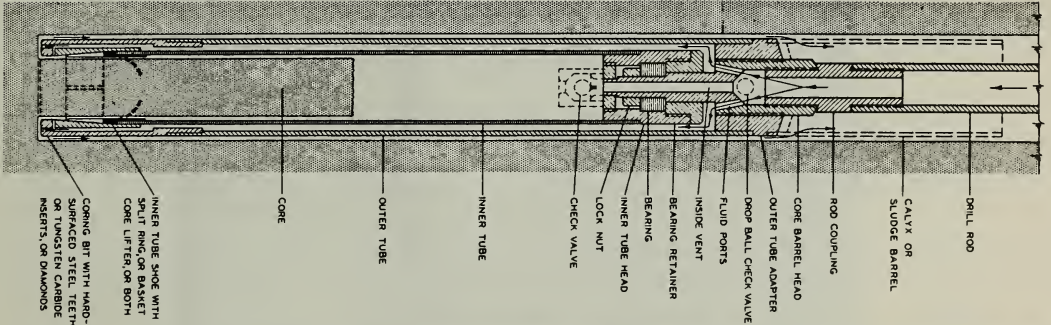
## SINGLE TUBE CORE BARREL



## RETRACTED INNER BARREL



## BOTTOM DISCHARGE



## PROTRUDING INNER BARREL

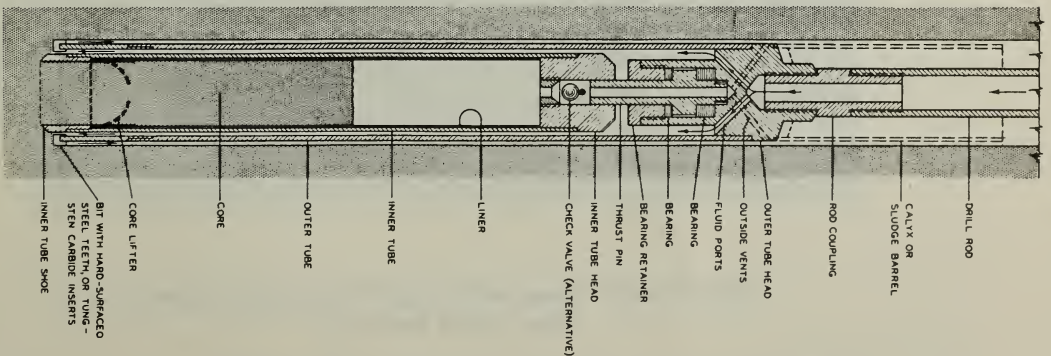


Figure 4-17 Single and Double Tube Core Barrels  
(op.cit. p.4-7)

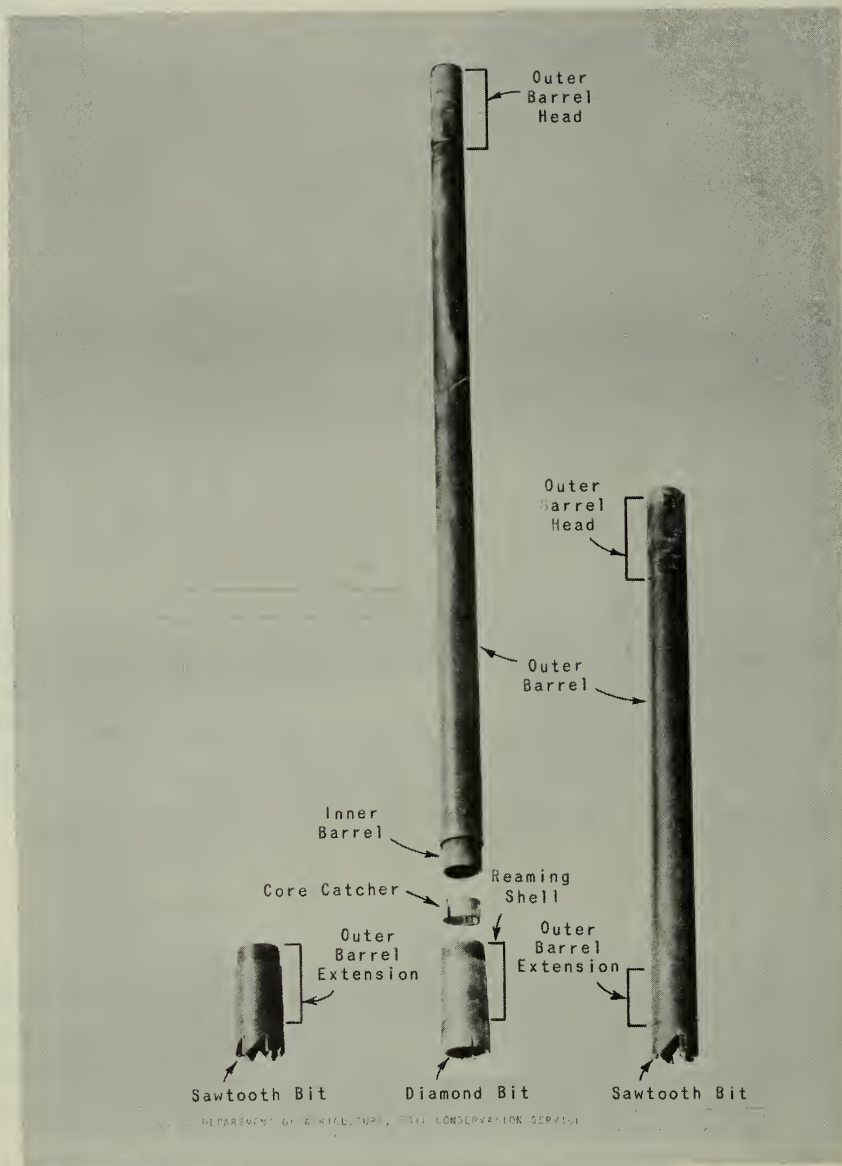


Figure 4-18 Long and Short (2-1/8 by 3-inch)  
Rock Core Barrels.

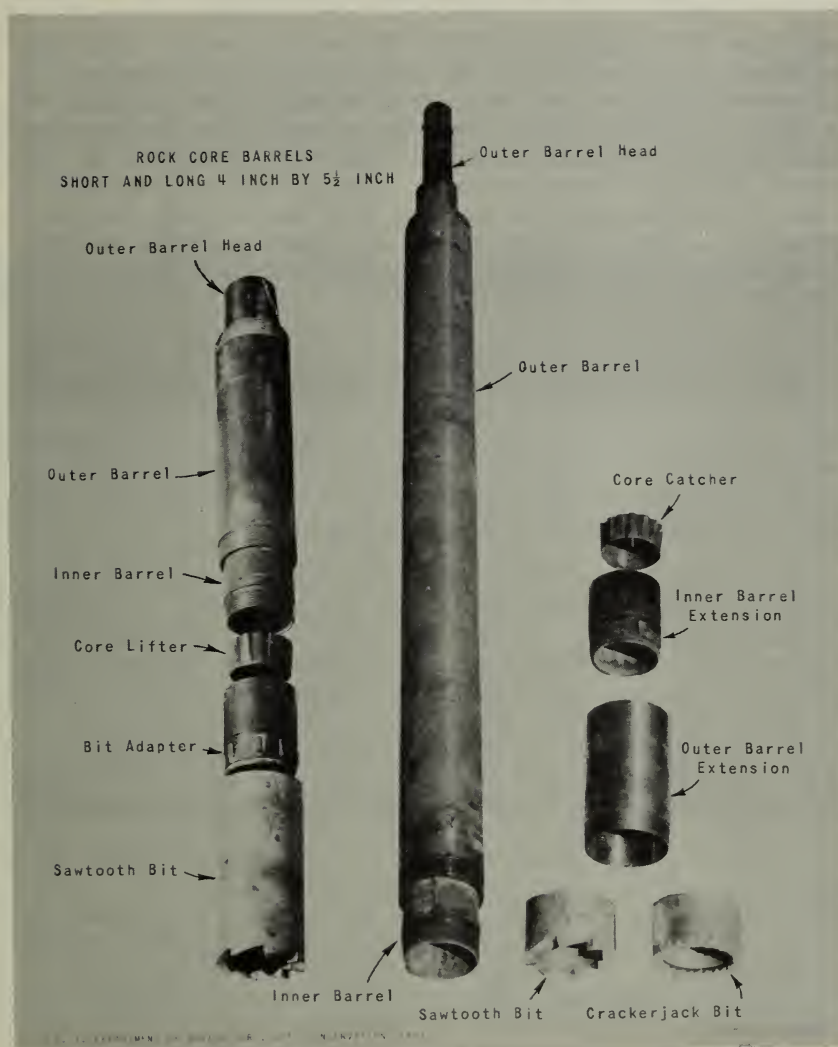


Figure 4-19 Long and Short 4"x5½" Rock Core Barrel

Carbology. Blank bits are also available for customers who desire to set their own bits. They are much less expensive than diamond bits, but are recommended for use only in soft rock. The rate of progress in hard rock is slow, and steel bits wear rapidly. For broken, medium hard formations, the "crackerjack" bit (figures 4-19 and 4-20) is useful.

Diamond bits are used for coring in all but the softest rock. They are of two kinds--set and impregnated. In set bits, industrial diamonds, usually West African Bortz, are set by hand or machine in a tungsten carbide matrix metal. Reaming shells are used to stabilize the bit and prevent it from whipping from side to side. They may or may not be required for Service geologic investigations. Diamond bits and reaming shells may be used interchangeably with steel bits on the core barrels described previously. When set diamond bits and reaming shells become worn, they are returned to the manufacturer for resetting. The remaining stones are salvaged in this process.

A drilling party should normally be provided with three sets of diamond bits: One for very hard formations (chert or quartzite), one for hard formations (sandstone or dolomite), and one for medium formations (cemented shale). Bits for harder formations use smaller stones, greater total weight of stones, and less water courses. Using each bit only in the formations for which it is designed results in much longer life for the bits. Typical diamond bits are shown in figure 4-21.

In impregnated bits the entire cutting edge of the bit is impregnated with small industrial diamond fragments. They are especially recommended for very hard, broken formations, which might result in "shelling" of diamonds from a set bit. Sand-blasting is sometimes required to expose new cutting points on these bits. They cannot be reset and have no salvage value. They are used until completely worn out and then discarded. They are recommended for Service use only where very hard, broken formations must be cored. If a reaming shell is used, it should be of the set diamond type, even though the bit is of the impregnated type.

#### Denison Barrels.

The denison barrel is similar in construction to the rock core barrel, but is designed to take a very nearly undisturbed sample of soil rather than rock. The barrel is of the double-tube, swivel-head type, with bottom discharge and the inner tube extending to or a little below the coring bit (figure 4-22).

The outer barrel should have interchangeable bits so that the inside clearance and the projection of the inner shoe below the outer barrel can be varied in accordance with the character of the soil.

The inner tube is provided with a plastic or metal liner to facilitate removal and proper preservation and shipment of the core. Samples are sealed in liners by means of expansion plugs (see figure 4-24), wooden plugs (see figure 4-23) or liner caps. Liner caps may be purchased from manufacturers of drilling and sampling equipment. Expansion plugs and wooden plugs must be fabricated locally.

A basket or spring-type core retainer is usually used. Several types, using a different number and flexibility of springs, are available, for use in different materials. The tapered, split-ring core retainer used in rock core barrels is not satisfactory for use in soil. A check valve is provided to reduce pressure over the core during withdrawal. The coring bits used usually have hard surfaced steel teeth.

The denison type coring barrel is generally accepted as capable of taking the most nearly undisturbed samples possible in highly compacted, hard, stiff, uncemented or slightly cemented and fine-grained soils. It is not suitable for sampling gravel and cobbles. Its suitability for sampling



Figure 4-20 Tools Used for Disassembly of Core Barrels

certain types of low-density cohesionless silts and sands below the water table and very soft and plastic cohesive soils is questionable.

Denison type core barrels taking a sample of about two feet in length are recommended for Service use. Various diameters are available and have been

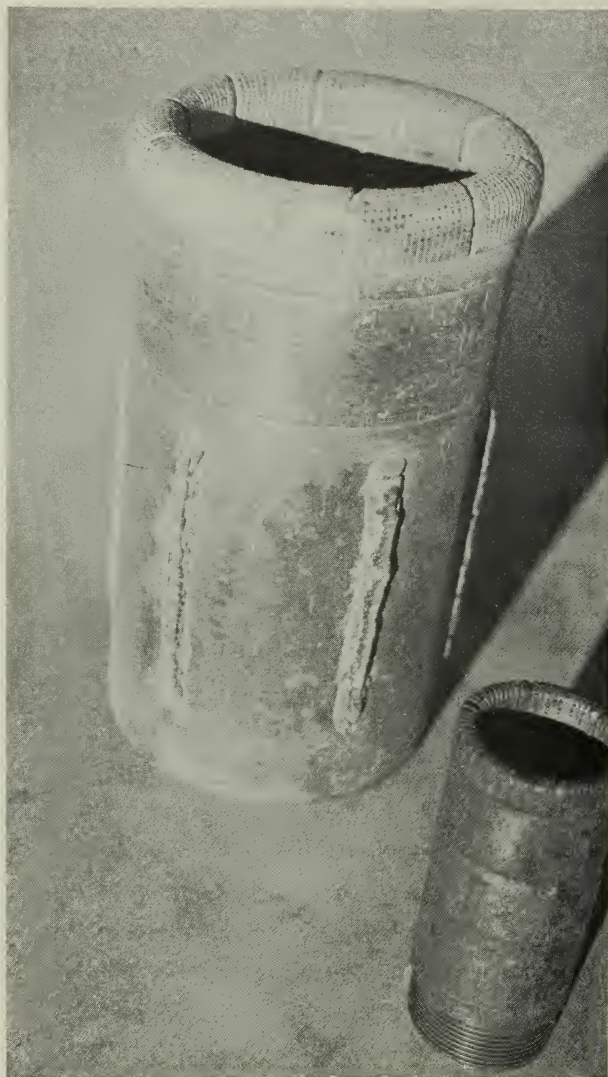


Figure 4-21 Diamond Bits,  
Larger with Reaming Shell

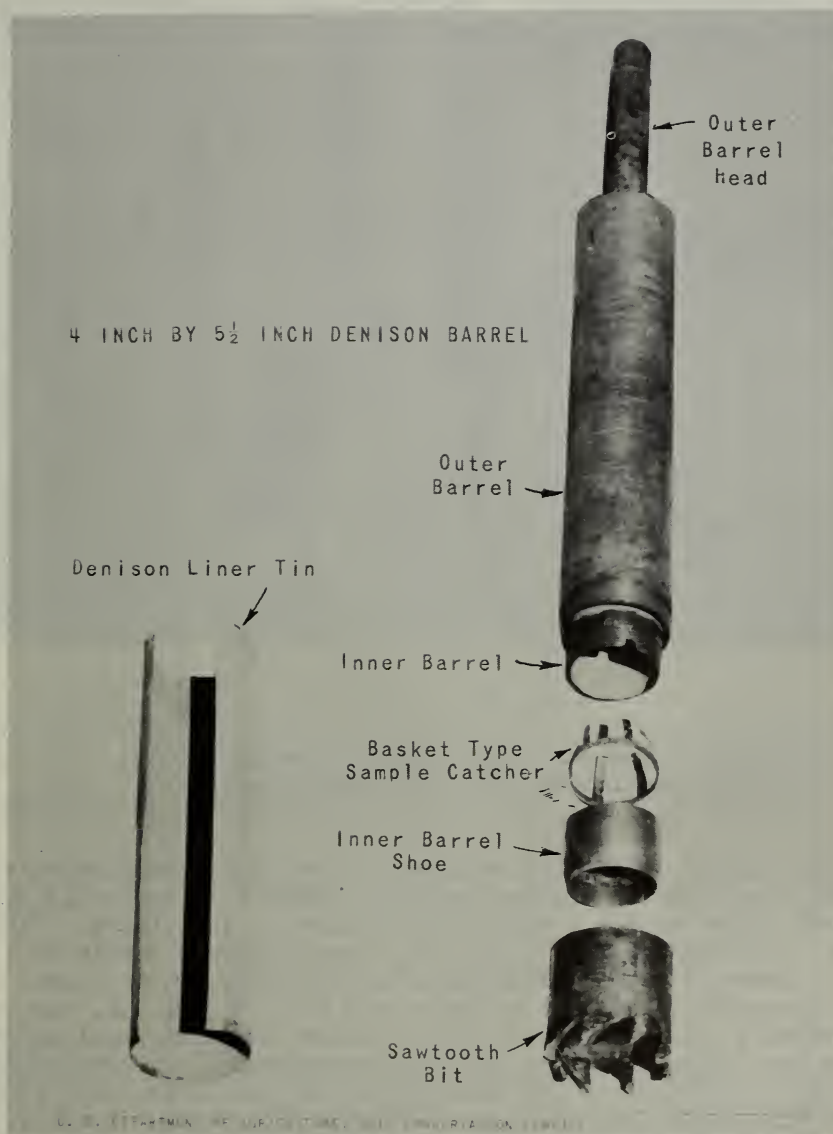


Figure 4-22 Denison Barrel

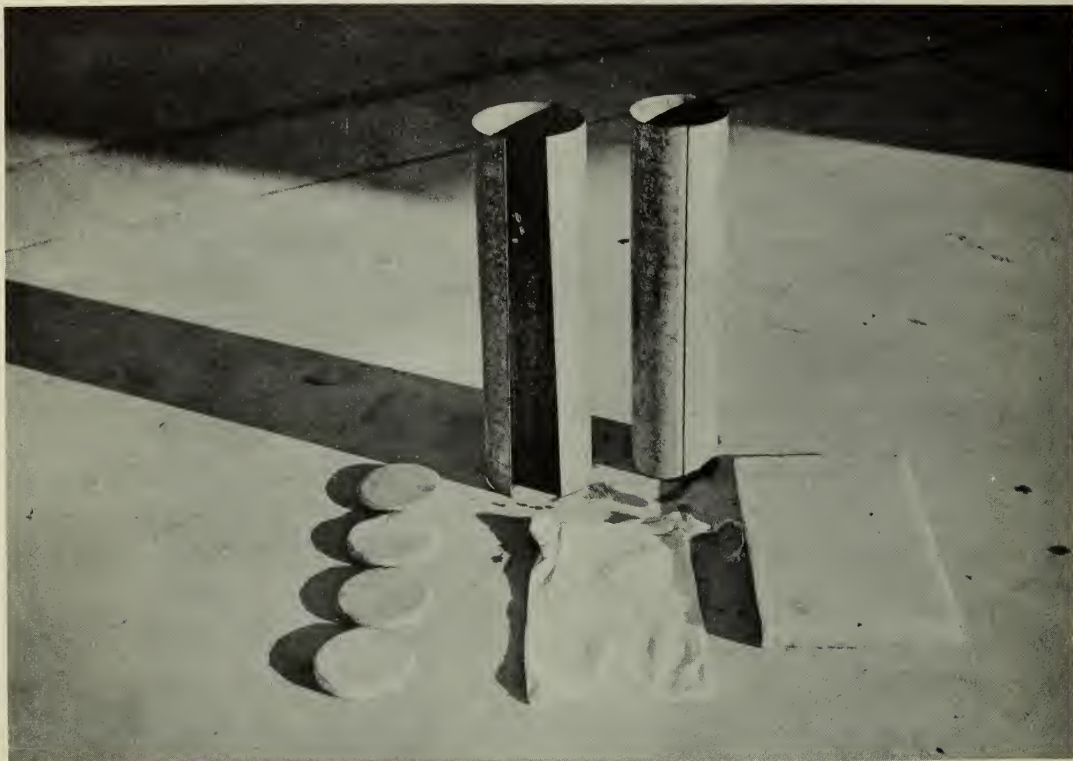


Figure 4-23 Denison Liner Tins, Wooden End Blocks,  
25-lb. Sample Bag and Microcrystalline Wax.

used by the Service. The size recommended for Service work depends upon the kinds of undisturbed samples desired. Samples for conducting tri-axial shear tests require a minimum diameter core of 5 inches. This requires a standard denison 7-1/2" O.D. barrel taking a sample of 5-7/8 inches in diameter. For consolidation and direct shear, a 3-inch sample is required. This may be taken with a 5-1/2 inch O.D. sampler which obtains a 4-inch core. Sectional 9-inch liners of seamless brass or rolled and welded stainless steel are recommended for Service use. Samples may be extruded at the laboratory from such liners with a minimum degree of disturbance and the liners returned for re-use. Two-foot, 20-gauge galvanized metal liners may also be used, however, such liners should have welded and soldered seams rather than crimped seams. Such liners must be slit open longitudinally at the laboratory which eliminates them from further use.

#### Pressure-Testing Tools.

The apparatus commonly used for pressure-testing foundations in rock consists of expansion plugs or packers set 5 feet apart, which may be

expanded to seal off sections of a drill hole. Water lines are so arranged that water may be admitted either below the bottom expansion joint or between the two expansion joints and are connected through a pressure relief valve, pressure gage, and water meter to a pressure pump.

With such an apparatus, zones of leakage may be isolated in drill holes and their capacity for transmitting water measured. Such information is used to appraise leakage conditions and estimate grouting requirements. Pressures employed must be limited to approximately one pound per foot of depth of the expansion plug to avoid damage to foundations resulting from excessive uplift.

So far as the Service is concerned, a leakage of water from a floodwater retarding structure is usually not considered a problem unless it endangers the dam. However, leakage from multiple-purpose reservoirs, irrigation reservoirs, and large farm ponds is a matter of concern. For Service geologic investigations of such dams, hydraulic pressure-testing equipment may be required if questionable rock foundations are encountered.

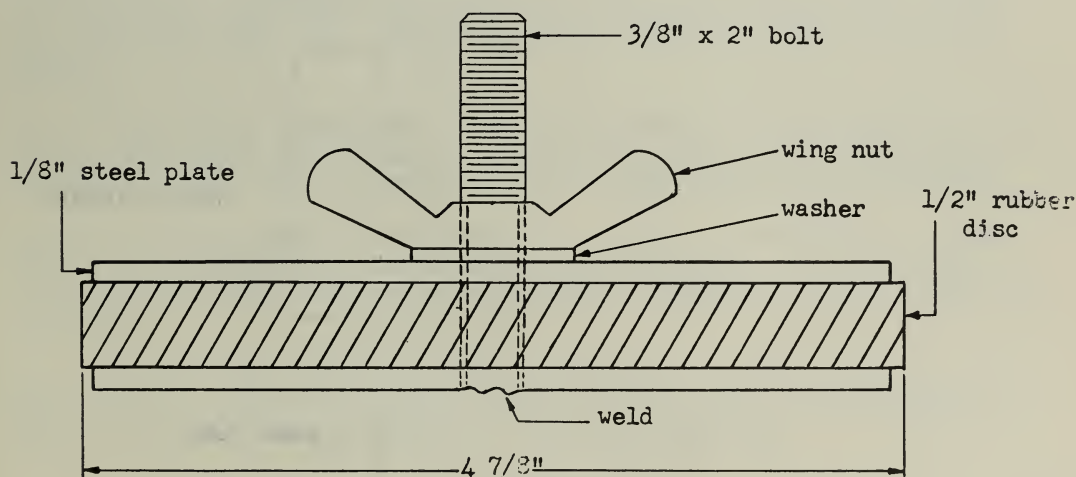


Figure 4-24 5-inch Expansion Packer

#### Drive Hammers.

Drive hammers are required for standard penetration tests and driving casing (figure 4-25). A 140-pound hammer is required for the standard penetration test and heavier hammers are used for driving casing and removing casing.

#### Drill Rod and Couplings.

The "W" group of drill rods and couplings are currently used extensively by the Service and are recommended for Service drilling rigs. Normally drill rod of "BW" size, 2-1/8 inches outside diameter and of "NW" size, 2-5/8 inches outside diameter, will have adequate strength.

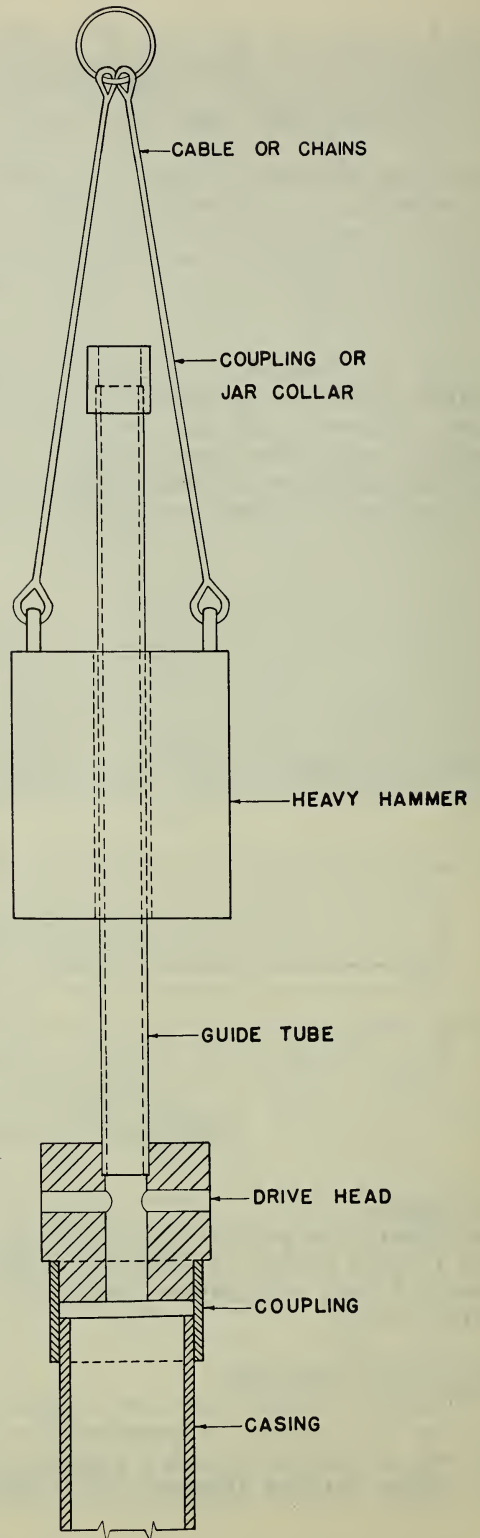


Figure 4-25 Drive Hammer and Drive Head Diagram

Many types of tool joints or couplings are available. Some types, such as tapered thread joints, are subject to greater wear and to splitting of the female joint or box than others. The joint recommended for Service use is the non-tapered flush joint, three threads per inch. This is shown in figure 4-15.

Drill rod is normally manufactured with a box on each end. It is good practice to use a drill rod substitute on each end. The female connection is made by means of a pin to box substitute screwed into one end of the pipe. The male connection is made by means of a pin to pin substitute screwed into the remaining end. When the substitute becomes worn or damaged they can be replaced, rather than replacing the entire section of drill rod.

Drill rod of ten-foot length (ten feet, six inches with substitutes on both ends) is best adapted for Service needs. Although twenty-foot lengths of drill rod are not used, it is desirable for the mast to be of sufficient height to handle at least two ten-foot lengths with substitutes (21 feet). This greatly expedites placing and removing tools from deep bore holes. The number of sections needed for a particular drilling rig will depend on the maximum number of feet which might be bored with the rig (seldom more than 100 feet) plus several spare rods for replacement in event of damage.

Solid drill rods are used with power augers since water circulation is not used. Flush joint drill rod of standard "AW" size, 1-3/4 inch outside diameter, or "BW" size, is satisfactory for most power auger operations.

Since the joints need not be watertight, a simple joint such as a square pin and box, connected by drive pin, is satisfactory. Normally three 10-foot, two 5-foot, and two 2-foot lengths of drill rod will be ample for augering.

With the newer types of power augers which have a 14-foot spindle, it is unnecessary to add drill pipe for at least 90 percent of the drilling. This, of course, greatly speeds the drilling operations.

### Drilling Rigs

#### General.

Rotary drilling rigs, may be driven by a power take-off from the mounting truck, or they may have an independent power unit to operate the drilling mechanism. The latter arrangement is preferable, as it avoids excessive wear on the truck engine. Some rigs also have a third independent power unit to run the mud pumps, so that drilling fluid circulation can be controlled independently of the speed of the drill.

Some rigs have a retractable drill head and some do not. If the larger diameter thin-wall tubes and denison and rock barrels are to be used, the retractable drill head is necessary. This enables the barrel to be raised and swung out onto a rack for disassembly and removal of the core. If the drill head is not retractable or cannot be swung out of the way, the larger diameter sampling barrels cannot be used because they will not

pass through the rotary table opening. In addition, if the rotary rig is to be used for installation of pressure relief wells at dam sites, it must have a retractable drill head to set and remove the temporary 16 or 18-inch casing used in relief well installations.

Some drilling rigs are equipped for angular drilling to one side or the other. This eliminates the necessity for leveling up the mounting truck before drilling on sloping ground and provides a means of boring an inclined hole.

The speed of rotation of the drill varies widely in different rotary drilling rigs. For diamond core drilling a rotational speed of at least 400 to 600 rpm, using a 4-inch by 5-1/2 inch bit, is desirable in order to reduce diamond wear. Lower rpm speeds are required for larger barrels and higher speeds for smaller barrels in order to maintain the same peripheral speed.

Various sizes of pumps are available. The larger capacity pumps are damaged less by sand passing through them. They are also less apt to become clogged with sawdust, leaves, or similar materials when these are added to the drilling mud to assist in sealing the walls of a hole.

The mounting truck is usually optional, the only requirements being that it have adequate power, wheelbase, and transmission for the rig contemplated.

It should have all-wheel drive, a front-mounted winch, brush guard and belly plate.

Rotary drilling rigs are largely custom built with standard accessories to the customer's specifications. Hence, almost any combination of the features desired, including mast heights is possible. Tool boxes, drill rod racks, barrel and bit racks, auxiliary gasoline tanks, and spare tires, are placed in accordance with the customer's wishes. The range in prices given for some rigs reflects the difference between power take-off and an independent power unit. A rig with an independent power unit costs about \$2,000 more. A typical rotary drilling rig is shown in figure 4-2.

Similarly, power augers may be obtained with power take-off or an independent power unit, and with considerable choice as to the mounting truck or jeep and other details. An auger should be capable of boring to a 14-foot depth without adding drill rod. This greatly reduces time required for drilling out a dam site. The independent power unit is preferable from the standpoint of longer lasting engine life. A power auger is shown in figure 4-1.

Power auger mounting trucks also should have all-wheel drive, a front-mounted winch, brush guard and belly plate. Since water is sometimes required to make the material adhere to the bit, a 100-gallon water tank should be mounted on the power auger truck.



Figure 4-26 Combination Water and Tool Truck (500-gallon Capacity).

#### Water and Tool Trucks.

It is possible to mount a small water tank of 200 or 300 gallon capacity on the rotary drilling rig. Under many drilling conditions, however, this amount of water will not last long and it becomes necessary to interrupt drilling operations each time that more water is needed. Considerable drilling time may be lost if water must be hauled long distances. The amount of water required for a particular job depends on the type of drilling rig and on the type of formations being drilled. In very pervious formations, such as gravel or vugular limestone, it is very difficult to maintain circulation because of water losses in the formations, and a large amount of water can be consumed in a very short time. Hence, it is usually more desirable to have a separate water and tool truck.

Normally a water and tool truck of at least 500 gallon water capacity is required. The mounting truck should have all-wheel drive, a front-mounted winch, brush guard and belly plate. A vacuum pumping unit, operated from the truck motor or a separate unit, should be provided for filling the tank. The tank must contain baffles to prevent surging either lengthwise or

sidewise. Tool boxes and racks may be placed wherever desired. Figures 4-26 and 4-27 show a typical water and tool truck.

#### Other Equipment.

**Hole bailer.**--Aside from the tools normally provided with a drilling rig, several other items of equipment are needed for geologic investigations. In making measurements of ground-water level, a hole bailer is required. The outside diameter of the bailer should be 1 inch smaller than the hole diameter and preferably 5 feet long. It should have a dart bottom valve. A bailer of this type is shown in figures 4-28 and 4-30.

**Hole cleaner.**--Hole cleaning tools perform the function of removing loose soil and rock particles from the bottom of a hole before samples are taken. Various types of cleaning tools have been designed to operate in various soil conditions. These tools include jetting augers, with outside diameters from 3-1/8 to 5-1/2 inches; standard augers with outside diameters from 2 to 5-1/2 inches; sludge barrel types with outside diameters from 2 to 4-1/2 inches; and others (see figure 4-28).

**Sample catch pan.**--A sample catch pan similar to that shown in figure 4-29 is needed when augering with either a rotary drilling rig or power auger. When the auger bit is raised, the pan is placed under it and the soil knocked into it with a spade. The material from the pan is then dumped in piles representing 1.0 to 2.0 foot increments for logging and sampling. Normally this pan should measure about 2 feet by 2 feet. It should be obtained from local sources.

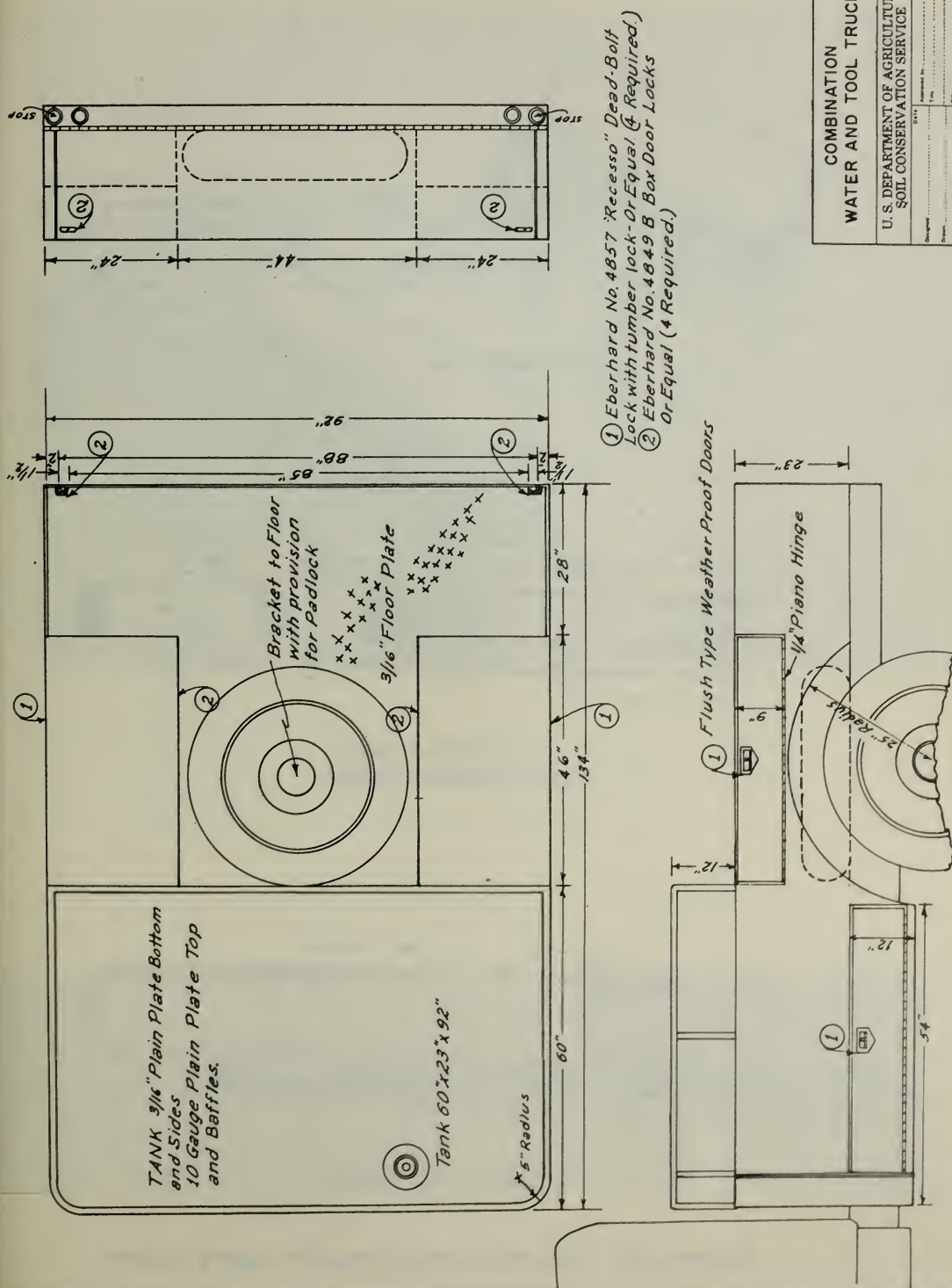
**Barrel rack.**--A barrel rack will also be needed to remove cores from denison and rock barrels. A typical rack of this type is shown in figure 4-32. It should be designed to fit the size of barrels being used. It also is not available on the market and must be specially fabricated.

**Slush pits.**--Portable, or tank-type, slush pits are sold by some drilling equipment companies. These are not very satisfactory for Service investigations, which involve shallow drilling and frequent moving from hole to hole except in cases where hard rock prevents or gravel beds prohibit digging of adequate slush pits. Each time the drilling rig is moved, the mud must be removed from the tank to make it light enough to move. It is usually easier and faster to dig a small pit or sump for the drilling fluid at each hole. This, of course, is not required for auger boring.

### Drilling Techniques

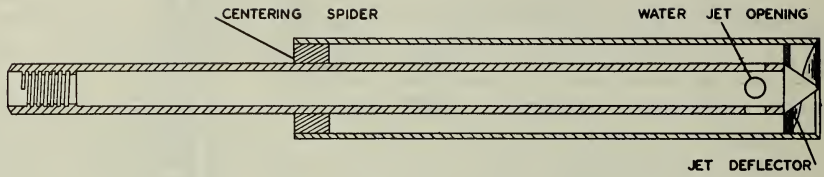
#### Stabilizing Bore Holes.

Temporary casing or lining of the bore hole with steel pipe is the most positive method of stabilizing a bore hole. It is normally required for certain methods of advancing holes such as cable tool. However, because of the expense and time consumed by casing rotary core drill holes, it normally is not used in Service work where holes are stabilized with drilling mud. Casing is required for

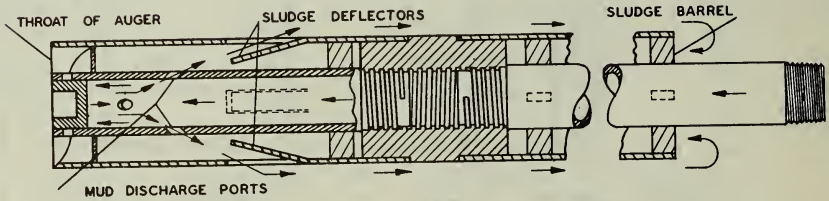


COMBINATION WATER AND TOOL TRUCK			
U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE			
Designed by	Checked by	Drawn by	Scale
W.C.B.	W.C.B.	W.C.B.	5-57
Project	Sheet	Number	Date

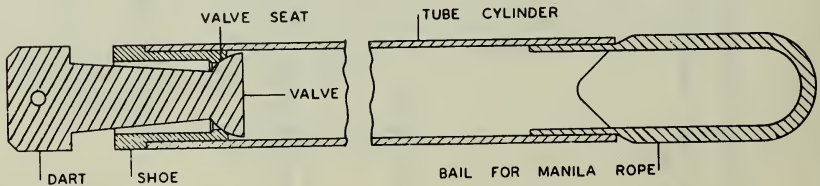
Figure 4-27 Combination Water and Tool Truck - Schematic



Standard Clean-out Auger



Clean-out Auger  
With Sludge Barrel



Dart Valve Bailer

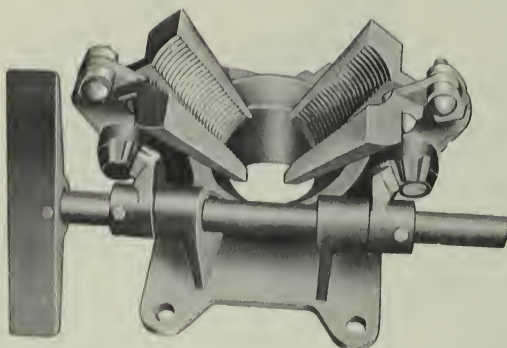
Figure 4-28 Hole Bailer and Clean-Out Augers (Acker)



Figure 4-29 Sample Catch Pan



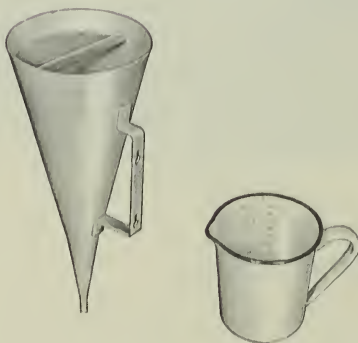
Figure 4-30 Hole Bailer



Safety Foot Clamp



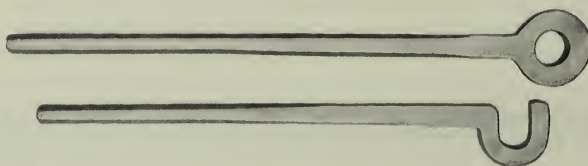
Drill Rod Taps



Marsh Funnel



Core Catcher



Holding Irons

Figure 4-31 Miscellaneous Equipment

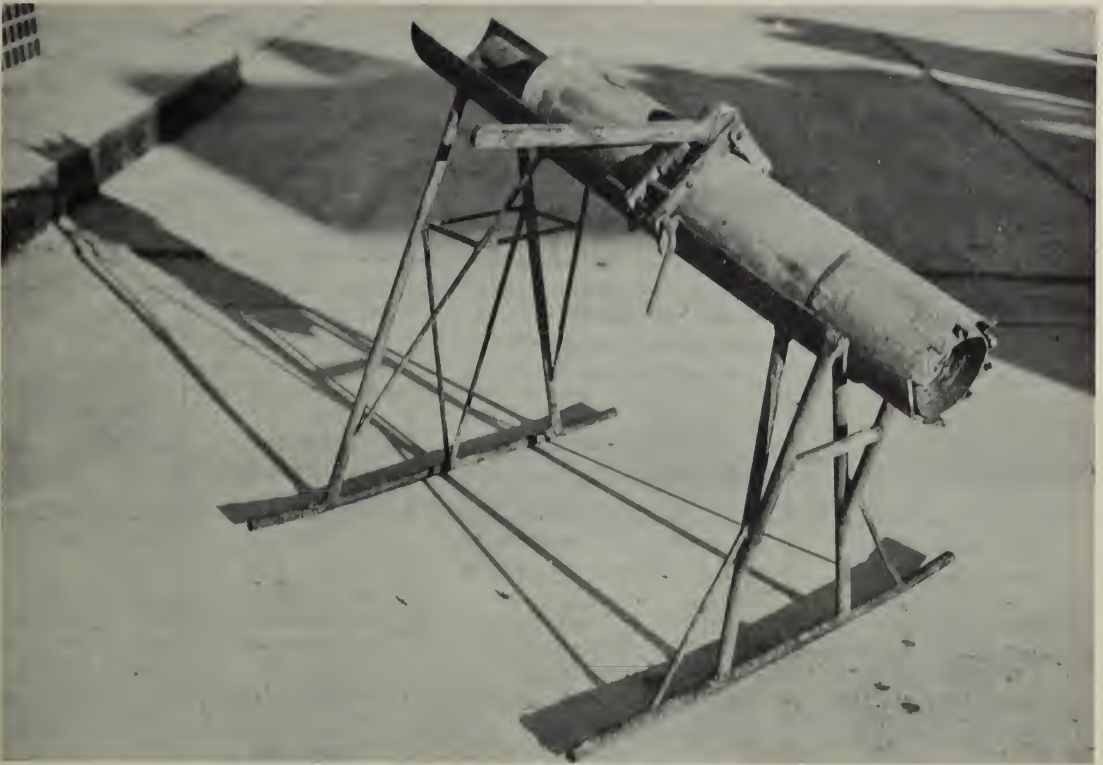


Figure 4-32 Denison Barrel and Rack

the installation of relief wells. In this respect the purpose is to hold back very wet, loose formations while the filter pack material is being placed around the well screen.

#### Drilling Fluids.

An uncased shallow bore hole of the type usually drilled by rotary core drilling methods ordinarily can be stabilized with a properly proportioned drilling fluid or "mud" (Table 4-3). Drilling muds, known by such names as Volclay and Aquagel, consist of highly colloidal, gel-forming clays. Native clays may also be added to the drilling fluid. The drilling fluid forms a relatively impervious lining or "mudcake" on the side walls of the bore hole. Weighting materials such as ground barite may be added to the drilling fluid to increase its specific gravity and prevent caving of the hole in troublesome soils or when the fluid must carry very coarse-grained materials in suspension. New types of drilling fluids have recently been developed which, in effect, cement the inside of bore holes to the extent that they serve the same purpose as metal casing. Drilling mud is not added to the circulating water in rock coring.

Drilling fluid may be lost when cavities or highly permeable strata are encountered. This loss can often be stopped and circulation regained by adding straw, leaves, or seed hulls to the fluid.

Table 4-3

Approximate Proportions of Mud Mixtures <sup>1/</sup>

Purpose of drilling mud	Approximate proportions of material per barrel of water <sup>2/</sup>	Viscosity <sup>3/</sup>	Descriptive consistency
Assisting cutting operations by the sampler	10 to 30 pounds of bentonite	Variable as needed	Variable as needed
For lifting cuttings from hole	10 to 15 pounds of bentonite for fine-grained soils	Slightly higher than water	Thin cream
	30 pounds of bentonite for coarse-grained material	About 1.3 times the viscosity of water	Very thick cream
For supporting the drill hole	30 pounds of bentonite and 5 pounds of barite	About 1.3 times the viscosity of water	Very thick cream
For assisting to hold the sample in the sampler	10 to 30 pounds of bentonite and 0 to 10 pounds of barite	Slightly higher than water to 1.3 times the viscosity of water	Thin cream to very thick cream

<sup>1/</sup> (U.S.B.R. Earth Manual, Tentative Edition with Revisions, 1951, 1958)<sup>2/</sup> One barrel equal to 50 gallons.<sup>3/</sup> Viscosity is measured by a Marsh funnel which is calibrated with water at 72° F. The time required for a given amount of water to flow through the funnel is considered as 1.0. The value listed above is the relative time for the same amount of mud mixture to flow through the funnel.

Two slush pits should usually be dug downslope from the drill hole, with a small channel connecting them and the drill hole. The drilling fluid then will flow from the hole to the first pit, where the coarse material will settle out, and then to the second pit, where the mud can be picked up for recirculation. Sand should be removed from the pits as it accumulates. If this is not done, the pump and the sampler may become clogged with sand. If coarse material is not present, one slush pit may suffice.

#### Selection of Tools.

In the investigation of a dam site, the drilling method should be adapted to the complexity of the geology and the type of information desired. In areas of rapid change, as in alluvial deposits on the centerline of the

dam, it may be necessary to obtain split-tube or split denison <sup>1/</sup> samples from a number of borings before an accurate description of the strata can be given.

Auger boring is done in all representative materials in the borrow area which occur in thick enough strata or large enough areas to be worked separately. Augering can be accomplished by use of an auger that is suited to the type of material encountered in the boring. Open (slat-type) augers with a high pitch cutting bit are best suited for clays and plastic materials. Closed (cylindrical-type) augers are best for sandy and gravelly materials. Semi-closed type augers are used for soils of intermediate texture. If the material is dry, water should be poured into the hole at such a rate that it will lubricate the bit. Excessive quantities of water will tend to make the mixture soupy and unsuitable for the taking of samples for field study.

Undisturbed samples such as those obtained by rotary drilling with a denison barrel, are required to evaluate foundation characteristics such as volume-weight and original moisture and for more detailed laboratory tests such as shear strength, consolidation, and permeability.

#### Rock Coring.

General.--The primary objective in rock coring for dam site investigations is to recover all of the rock cores intact. This is necessary in order to determine volume of rock excavation, possible uses of rock material for riprap, drainage blankets, or other purposes, depth of cutoff trench required, stability of foundation, and similar problems. This objective can be fulfilled only by the proper choice and operation of the core drilling equipment. If the proper standards are maintained, recovery of rock cores plus the drilling logs will provide a basis for interpreting the presence of caverns, fractures, fissures, or faults which might affect the safety of the foundation, and for determining the hardness and possible uses of rock in the required excavation.

Bit speed.--Excessive bit speed will result in chattering and rapid wear of the bit and will break the core. A low bit speed results in a slow rate of progress and higher wear on diamonds. As the equipment becomes worn and the drill rods poorly aligned, it may be necessary to decrease the bit speed in order to avoid excessive vibration, whip, and chattering of the bit with consequent danger of breaking the core and damaging the bit. Higher speeds should be used in hard rock and lower in soft or broken rock.

Bit pressure.--The rate at which the coring bit is advanced depends upon the amount of bit pressure used. This pressure must be carefully adjusted to the character of the rock, the type of bit, and the bit speed. Excessive bit pressures, especially in soft rock, will cause the bit to plug and may possibly shear the core from its base. The bit pressure is controlled by a hydraulic feed on the drilling machine. For the shallow

<sup>1/</sup> When liners are opened in the field for sample inspection they are called "split denison".

drilling in which the Service is engaged, the weight of the drilling column will never exceed the optimum bit pressure except in very soft rock.

In hard rock a high feed pressure on diamond bits not only increases the rate of advance but also keeps the bit sharp and free cutting. A low feed pressure in the same rock tends to polish the diamonds. In softer rock the best results may be obtained with relatively low feed pressures.

Drilling fluids.--Clear water is generally preferred to drilling fluid in rock coring. Water is cheaper and requires smaller fluid passages and pump pressures, and the rock cuttings are generally so fine that they remain in suspension in water and are easily carried to the surface. In some cases air circulation is used with coring.

Where water is used, the flow of the return water should be regulated so that the cuttings are just carried out of the hole. Water may be scarce and nothing is gained by using more than is necessary. If too much is used, velocity across the bit face is increased and a scouring action results in bit erosion. The metal holding the diamonds in a bit may be scoured away, leaving the diamonds exposed and easily pulled out. The flow should be increased when softer rock is being cored and larger sized cuttings are formed. However, it must not be great enough to wash away the core.

If water pressure begins to build up as indicated by the relief valve, there is generally some restriction at the bit face or in the core barrel where some core has plugged. "Plugging" may occur where the rock is fractured or contains many seams. In this event a piece of rock wedges in the bottom of the core barrel and not only prevents additional core from entering the barrel, but also restricts water flow, blowing open the relief valve.

The barrel may sometimes be cleared by lifting off the bottom a few inches and letting the hole wash. The one sure solution to a plugged barrel is to pull out the tools and clean out the barrel. Sometimes it is best, if plugging is a problem, to drill through seams of broken rock with a roller bit. This method has the disadvantage, however, that no core is obtained.

If a diamond bit is run without sufficient cooling by water (or air circulation in some cases), it will burn and stick fast rapidly, and may be ruined in just a few feet of drilling.

A serious condition frequently encountered is the loss or "running off" of return water into cavities in the rock, causing what is known as a "blind hole". This condition can often be corrected by adding leaves, grass, or cotton hulls to the water. Such materials will often seal seams and cavities in the sides of the hole.

Hole cleaning.--The hole should always be washed before starting to drill, as well as before pulling out the rods and tools. It should be kept in mind that at the end of a run there is a column of water

extending the full length of the hole carrying the cuttings in suspension. If the pump is stopped immediately these cuttings will settle to the bottom and when the bit is lowered it will rest upon a thick layer of mud instead of clean rock. The pump should be kept running until the return water is clear. When drilling through soft rock and there is a chance of washing the core away, the core barrel should be raised at least six inches before washing.

**Core recovery.**--Percentage core recovery is an important factor in rock coring operations. The rock below the core barrel and in the lower part of the core is subject to torsion and vertical forces. The core is cut with a slightly smaller diameter than the inside diameter of the core barrel inner tube and, excepting cores of certain soft and swelling rocks, there is very little inside wall friction as long as the core is unbroken. However, the inside friction is activated when the core is broken and rock fragments become wedged between the core and inner barrel. A greater part of the feed pressure may then be transmitted to the core and to the rock directly below the core. The result is that weak sections of the rock and possibly all of it is broken up and removed by the circulating water instead of entering the core barrel.

Since the torsional moment of resistance of the core increases with the cube of its diameter, an increase in diameter is very effective in reducing breakage and increasing the recovery ratio and the length of core obtainable in a single operation. For Service dam site investigations, the "NX" barrel (2-1/8 inch diameter core) is the smallest core barrel which should be used, mainly because of core recovery problems.

Other factors may also influence core recovery. Faulty core catchers may cause the loss of much core. Excessive water use may wash soft materials away. Warped drill rods or worn guides may result in undersize or broken and ground up core. The proper selection of bits, although primarily influencing the rate of drilling, has some application to core recovery, particularly in soft formations. For example, a steel bit is usually more effective in shale, both in rate of drilling and amount of recovery, than a diamond bit. Diamond bits generally have better recovery ratios than steel bits in harder rock.

Obviously, no core can be recovered when openings such as caverns, solution channels, or large open joints are encountered. The presence of such cavities can often be recognized by the drilling tools dropping several inches, suddenly, accompanied by a loss of water circulation.

In removing the core from the barrel it may be necessary to tap the barrel lightly with a hammer. The core should be laid out exactly as it comes out of the barrel, and allowances made for seams or fissures run through. The core barrel should be thoroughly washed and the joints lubricated before reassembling.

**Disposition of core.**--In Service dam site investigations cores are usually left on the ground beside each hole drilled unless sent to the laboratory for analysis. Most rock coring will be required in the emergency spillway or other areas where rock excavation is anticipated. Samples of easily

weathered rock cores, such as shale, should be stored at the nearest Service office. If they are left outdoors and allowed to weather, they may give prospective contractors for the dam an erroneous impression of their original hardness. Cores sent to the laboratory for analysis should be packed in core boxes for shipment.

General considerations for rock coring.--The following general considerations should be observed in rock coring work:

- a. Always lower rods and tools carefully. Dropping an expensive diamond bit on the bottom of the hole can cause serious damage.
- b. Don't let the drill bit bounce or vibrate on the formation being cut.
- c. Don't start the bit while it is resting on rock. Spin it into the formation, slowly and cautiously at first. Increase the feed after 4 to 6 feet. The top rock is usually weathered, fractured, and seamy. Remember the old axiom among drillers that "more damage is done to the bit in the first five feet than in the next hundred". Also, the "solid rock" being drilled could be a boulder or projecting ledge, after which the bit could be ruined running through gravel and cobbles.
- d. Don't slide a diamond bit over old core - spin over it. This will result in less diamond loss. A roller bit should be used if much core or caved material is left in the drill hole.
- e. Don't throw a diamond bit into the tool box. Wash it off at the end of a run, disconnect it from the barrel in transit, and put it away carefully. Never use a wrench on the diamond area. It is a diamond tool - treat it as such.
- f. Don't force a diamond bit. The diamonds are set for maximum performance. If penetration rate in a uniform formation decreases, with bit speed and feed rate remaining the same, take off the bit. More damage is done to diamond bits through pressing to obtain another barrel of core than in any other way. If the bit is continued in service too long, the exposed diamonds are pulled out, and the loose stones riding around the bottom of the hole can quickly destroy the entire bit.
- g. Check the rods and joints for leaks. Split or improperly connected rods can seriously reduce the circulation and cause overheating of bits.
- h. Check the core barrels to make certain they are straight. Pay particular attention to the core barrel head.
- i. Feed the drill with a steady pressure. Increasing or decreasing pressure and bit speed in a given formation normally will not increase rate of penetration but it will increase operating costs.

- j. Keep an accurate record of the lengths of drill rods and tools in use. Trusting to memory can be expensive. In trying to remember odd lengths of drill rod, many a driller has become confused and dropped a string of tools 10 or 15 feet because he thought they were already on the bottom.

#### Soil Coring.

Inserting bit.--In coring soils, as contrasted with rock, the sampler should be kept at a safe distance from the bottom during any final flushing of the bore hole which may be required. The circulation of drilling fluid should be stopped while the sampler is lowered the remaining distance and seated on the bottom. The circulation should be established before rotation of the barrel is started, and both the bit speed and rate of circulation should be increased slowly to their optimum values.

Bit speed.--Operational procedure in soil coring must be determined by trial for each soil condition. The rate of penetration, the speed of rotation, the length of cutting bit, the consistency of the drilling mud, and the pump pressure are all dependent upon soil conditions. The speed of rotation for soils and soft rock may vary from 40 to 125 rpm.

Bit pressure.--The pressure on the coring bit and its rate of advance or feed must be carefully adjusted in accordance with the character of the material encountered, type of bit, and bit speed. Too high a bit pressure and rate of feed may damage the bit and cause plugging of the bit and fluid passages and failure of the sample before it enters the barrel. Too low a bit pressure and slow or intermittent feed may expose the core to excessive erosion and torsional stresses. As the sample enters the inner barrel wall friction increases, and bit pressure must be increased to maintain a constant rate of advance. Generally, the rate of penetration should be no greater than the speed at which the outer barrel is able to cut.

Drilling fluids.--The pump pressure and discharge should be hand controlled for soils and soft erodible rock so that the rate of circulation of drilling fluid can be controlled independently of bit speed. If the rate of circulation is too slow, or the bit pressure too great, the bit and fluid passages will plug. If the flow is too great (this is often the case), erosion of the core and soil below the bit will result. In the latter case the drilling fluid may be forced to seek a path inside the cutting shoe, alongside the soil core, and through the vents, thereby eroding or removing part of the core. Generally, the pump pressure should be the minimum amount necessary to circulate the mud freely and carry the cuttings from the hole.

Drilling rigs with a separate power plant on the pump are the most satisfactory, because pump pressure can be adjusted independently of bit speed. On rigs which have a common power plant to turn the bit and run the pump, it is possible to bypass part of the fluid around the sampler. These rigs usually have a valve on the fluid line leaving the pump. A hose can be connected to this valve and run to the slush pit. The valve then can be partially opened so that some of the fluid flows directly to the slush

pit rather than through the sampler. By adjusting this valve it is possible to reduce the circulation of drilling fluid through the sampler by any amount, independently of the bit speed.

An undisturbed sample hole usually must be completed in one day. If fluid is allowed to stand in the hole overnight the remaining samples will be contaminated, unless the material being sampled is highly impervious.

Hole bailing.--Bore holes extending below groundwater level should not be pumped or bailed dry until drilling is completed, since the ground-water pressure on the mud lining likely will cause caving. Also, the flow of water through the bottom of the hole may disturb the soil structure. After drilling is completed it is often desirable to pump or bail out the hole to measure rate of permeability and static water table.

Hole cleaning.--If the hole sloughs or caves before sampling, the upper portion of the sample will be contaminated with material from the side of the bore hole. This portion of the sample should be removed before sampling.

## CHAPTER 5. UNDISTURBED SAMPLES

General

Sampling is one of the most important functions of the investigation program. The type, number, and size of samples collected depends upon the complexity of the area being investigated, the size and purpose of structure, and economic considerations in the event of structural or functional failure. In homogeneous foundations and borrow areas for small structures, sampling may be limited to a few representative samples. However, in areas of heterogeneous mixtures in the foundations and borrow pits, it may be necessary to sample at quite frequent intervals.

The type of samples collected for testing are divided into two general classes, (a) undisturbed and (b) disturbed (see Chapter 6).

Undisturbed samples are those in which the natural soil conditions are modified or changed as little as possible. Such samples are represented by natural clods, carefully excavated cylinders or cubes, or materials collected in tubes, cylinders, or cans. Laboratory tests for consolidation, shear, and horizontal permeability to determine stability of foundations require undisturbed samples.

Undisturbed samples can best be obtained from depths greater than 15 feet by core drilling equipment. In the absence of boring equipment, collection of undisturbed samples involves the excavation of test pits from which cubes or cylinders of soil can be obtained. Cubes, cylinders, or clods of soil may also be cut from the sites of open pits and cut banks both natural and artificial.

Detailed field notes must be taken with each undisturbed sample and should include the following as appropriate:

1. Hole number and location
2. Complete log of hole above and below samples
3. Method of drilling and size of hole
4. Type and size of test pit
5. Casing and drilling mud used
6. Ground water elevation
7. Length of drive and length of sample recovered
8. Size of sample (diameter)
9. Elevations or depths between which sample was taken
10. Method of cleaning hole before sampling

The sample itself should be marked with the following information:

1. Watershed, site number, and location
2. Date
3. Hole number and sample number
4. Elevations or depths between which sample was taken
5. Top should be clearly identified
6. By whom the sample was taken

#### Hand-Cut Samples

Hand-cut samples can be obtained from nearly all types of materials ranging from very soft to fairly hard, brittle soils with less disturbance than by any other means. They are limited, however, by accessibility. Trenches, test pits, large auger holes and other types of excavations are required for sampling depths up to 15 feet. Hand-cut samples are usually impractical to obtain at depths greater than this. Considerable care should be exercised in packaging hand-cut samples to assure their delivery to the soil mechanics laboratory without disturbance.

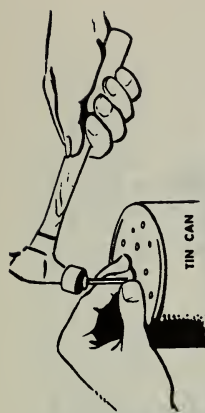
Hand-cut samples may consist of box samples, cylinder samples or chunk samples. Box samples are hand-cut and trimmed to cubical dimensions and sealed in individual boxes for handling and shipping. They should have a minimum dimension of 6 inches. Cylinder samples are short-tube samples from 4 to 8 inches in diameter and 6 to 12 inches long. They are taken by sliding a cylinder over a column of soil which is trimmed to approximate size in advance of the cylinder. Samples are sealed into the cylinder and are therefore less liable to damage or disturbance than are box samples. Chunk samples are of random size and shape and are broken away from the soil mass with or without trimming. They are difficult to package and ship but are simple to obtain.

Figures 5-1, 5-2, and 5-3 demonstrate the methods of obtaining and packaging hand-cut samples. Figure 5-4 demonstrates a method of obtaining an undisturbed cylinder sample using power excavating equipment.

#### Drive or Push-tube Samples

##### General.

Under certain soil conditions and types of samplers, drive samples taken with proper care and of adequate size can be used as undisturbed samples. The sampling tools and equipment for drive sampling have been discussed in Chapter 4, "Methods and Equipment". The term "drive sample" is a common nomenclature. In most cases, however, drive samples are collected by forcing or pushing sampling tubes into the soil. Forcing the tubes by means of intermittent blows with a hammer is not an accepted means of collecting undisturbed samples.

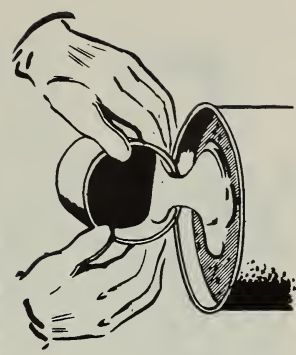


1. Punch holes in bottom of can.

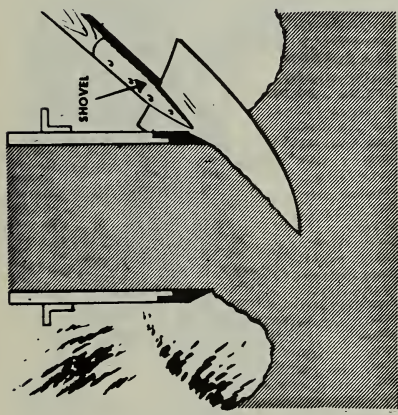


2. Excavate around can in the same way as for compaction mold and press down until soil penetrates to bottom of can.

3. Four paraffin in holes and seal bottom of can. Cut off sample with butcher knife and remove from hole.



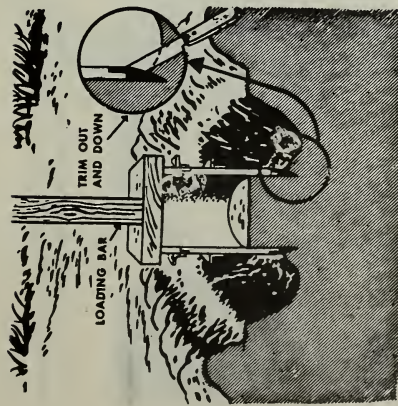
4. Cut surface about 1/2-inch below top of can and fill with paraffin.



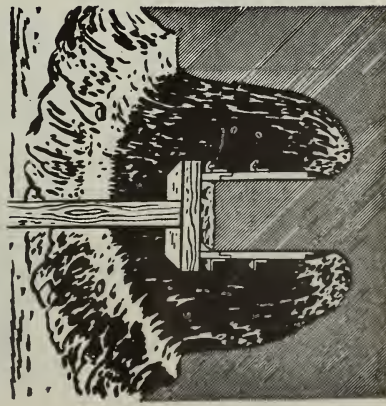
Cut off sample at bottom of mold with shovel, butcher knife, or wire saw and remove from hole.

Remove upper collar and trim top surface of sample; then turn mold upside down, remove sampling collar, and trim bottom. The top and bottom surfaces must be trimmed level with ends of mold. Protect ends with wood discs and tape around edges.

**NOTE:** If stones interfere, pick them out carefully and backfill with soil. Record this fact in log of sample whenever this is done.



Press mold down over soil firmly, using loading bar if necessary. Carefully trim soil away from sampling collar with knife. Cut downward and outward to avoid cutting into sample. The actual cutting to size is done with sampling collar.



Excavate trench deeper and repeat process until soil penetrates well into extension collar.

Figure 5-1 Methods of Obtaining Cylinder Samples

To obtain a chunk sample from a subgrade or other level surface such as the bottom of a test pit:



1. Smooth ground surface and mark outline of chunk.
2. Excavate trench around chunk.



3. Deepen excavation and trim sides of chunk with butcher knife.



4. Cut off chunk with butcher knife, trowel, or hacksaw blade and carefully remove from hole.

To obtain a chunk sample from the vertical face of a test pit or shovel cut:

1. Carefully smooth face surface and mark outline of chunk.



2. Excavate around and in back of chunk. Shape chunk roughly with butcher knife.



3. Cut off chunk and carefully remove from hole.



To seal chunk after removing it from hole:

1. Trim and shape rough edges with butcher knife.



2. Apply three coats of paraffin with paint brush. Allow each coat to cool and become firm before applying next coat.

**NOTE:** This gives adequate protection for strong samples that are to be used within a few days. Samples that are weak or may not be used soon require additional protection.



3. Wrap with cheesecloth or other soft cloth. If cloth is not available, reinforce with several loops of friction tape or twine.

4. Apply three more coats of paraffin.

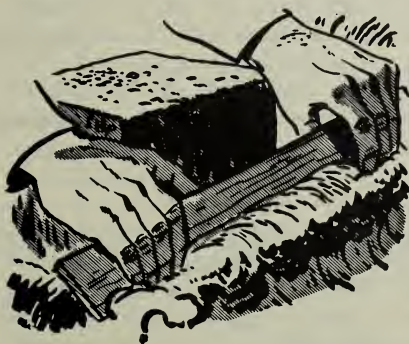


**NOTE:** A better method is to dip entire sample in melted paraffin after first brush coat is applied. This requires a large container and more paraffin, but gives a more uniform coating. By repeated dipping, paraffin can be built up to a minimum 1/8-inch thickness.

Figure 5-2 Chunk Samples

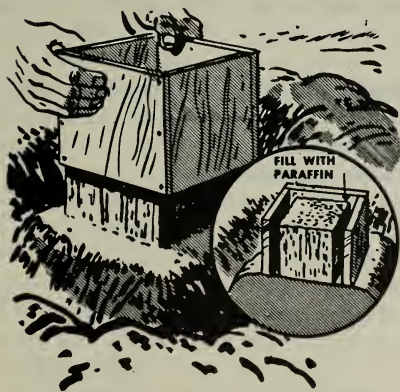
### Box Samples

Box samples are sometimes used for large undisturbed samples requiring extensive investigation. They can be firmly packed for shipment or storage, but require considerable paraffin.



To obtain a box sample:

1. Excavate as for a chunk sample, then trim sample to size slightly smaller than box.



2. Remove top and bottom from box and place over sample.
3. Fill sides with paraffin, then pour paraffin over top of sample and replace bottom.



4. Cut off sample, remove box containing sample from hole, and turn right side up.



5. Trim surface of sample and seal with melted paraffin, then replace lid.

Figure 5-3 Box Samples

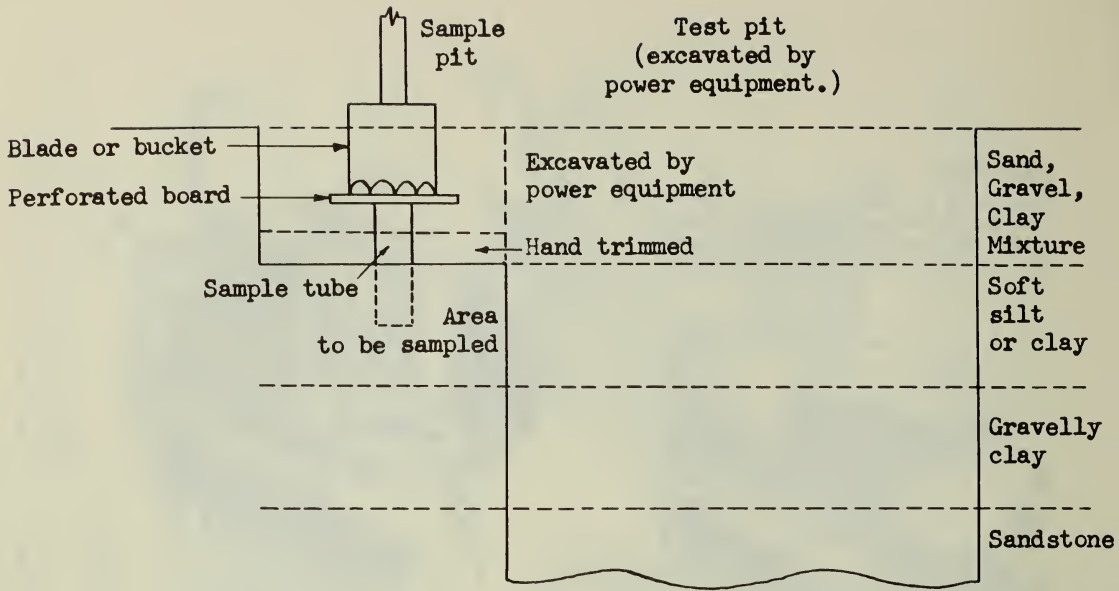


Figure 5-4 Undisturbed Sampling  
Using Power Equipment

1. Using power equipment, carefully excavate to within 10 inches of the top of the sample horizon. Remove the remaining material (10 inches) by hand tools.
2. Place the sampling tube in an upright position and place a perforated board on top.
3. Carefully center and level the bucket or blade on the board.
4. Jack the tube into the soil using a continuous, steady pressure.
5. Carefully remove the tube using hand tools.
6. Trim and seal the sample.
7. Dimensions of the tube are governed by the sample size requirements as outlined in this chapter.

The best sampling which can be done by driving methods is in fine-grained plastic or peaty soils. The method is not suited for sampling brittle or cemented soils, and gravelly soils. The amount of disturbance in drive samples depends to a great extent on the dimensions of the sample tube. For this reason the wall thickness, diameter, and length of the sample tubes are of primary importance.

The extrusion of samples from long, or small diameter open thin wall "Shelby Tube" samplers may be a source of sample disturbance. If the sample has expanded within the tube, greater force may be required to eject it than to take the sample originally. To eliminate further disturbance of the sample, the tube must be cut open to remove the sample. This may be accomplished by sawing the tube or by grinding a groove the length of the tube and removing a strip of metal with a key. This destroys the tube for further use and where a large number of samples is necessary for a low-cost structure, the cost of this method may be prohibitive.

#### Open-Drive or Push-Tube Samples and Sampling Procedures.

Because of the thinness of the sample tube walls, thin-wall solid-core drive samples are the least disturbed drive samples. Three-inch diameter tubes usually have a wall thickness of 1/16 inch and 5-inch diameter tubes about 1/8 inch. These samplers have no cutting shoe and therefore no bit clearance. Equipment may be purchased to swage thin-wall tubes to provide the necessary bit clearance. This may not be necessary if use of the sampler is limited to soft, loose, non-cohesive materials. Sampling tubes with 0, 1/2, 1, and 1 1/2 percent inside clearance of the inside diameter are needed for more cohesive materials (see table 5-1). Samplers which are subjected to high pressures require thicker walls. Tubes with the proper bit clearance should be available at the site to obtain adequate undisturbed samples for each type of material encountered. Cohesive soils and soils which are slightly expansive require varying amounts of bit clearance. Saturated and soft, loose sands, silts and clays may require little or no clearance. The clearance selected is that necessary to minimize drag or sidewall friction on the sample and to assist in retaining the sample in the tube. Table 5-1 presents general guide information for length of drive and bit clearance for various types of materials. The basic procedures for open-tube sampling, including solid tube and split tube with removable liner are as follows (see pages 4-17 through 4-24 for types of equipment):

1. Clean hole thoroughly. Loose material in the bottom of the hole will be picked up by the sampler.
2. Be sure drilling rig is anchored or heavy enough to counteract the pressure it is capable of exerting. This should be at least 8,000 pounds.
3. Sample tube must be smooth, thoroughly cleaned inside and outside, be properly sharpened, and have correct inside clearance for the type of soil being sampled. See table 5-1 for recommended clearances.

4. Drive should be made without rotation and with one continuous stroke.
5. Length of drive should be carefully measured and should be a few inches short of the sampler length to prevent compaction of the sample in the tube. See table 5-1 for recommended drive lengths.
6. Rotate sampler slightly to break off sample as pull is started.
7. Remove sampler carefully with a steady pull to avoid sample loss.
8. Samples are left in tube or liner for handling and shipping.

Drilling muds play an important part in sample recovery in that they help hold the sample in the tube by hydrostatic pressure, especially in cohesionless soils.

#### Piston Samples and Sampling Procedures.

The use of a piston sampler is the best method in loose, cohesionless material and for taking of samples from below the water table in cohesionless sands and soft, wet soils that cannot be recovered by open drive samplers (see table 4-1). Because of its many working parts and complicated operation the piston sampler should be used only where the open sampler cannot obtain an adequate sample.

Piston samples cannot be obtained from gravelly or cemented soils or soils too hard to penetrate. The basic principles of operation are the same as for thin-wall sampling with the exception of techniques for locking the piston which vary with the type of sampler. Additional rules are as follows:

1. The hydrostatic pressure of the drilling mud is aided by the suction effect of the piston, which pulls drilling mud into the end of the sample and seals it, making it more effective in holding the sample. The consistency of the mud should be such that about 1/2 inch of the sample is saturated with mud.
2. Tubes have little or no inside clearance and no sample retainers.
3. The sampler is assembled with the piston locked flush with the bottom of the tube.
4. Where a piston rod is used, it is connected to the piston either after the sampler has been lowered to the bottom of the hole or it may be connected piece by piece inside the drill rod while the sampler is being lowered.
5. The sampler is placed at the bottom of the bore hole and the piston unlocked by turning the piston rod clockwise five revolutions (this may vary with different samplers).
6. The piston rod is then secured to the drill rig or preferably to an independent frame and the sampler jacked under steady pressure into the material to be sampled.

Table 5-1. General Recommendations for Thin-walled Drive Sampling

Soil type	Moisture condition	Soil Consistency	Length of drive (inches)	Bit clearance (percent)	Recovery	Remarks
Gravel						Not recommended
Sand	Moist	Dense	18	0 to 1/2	Fair to poor	Recommended piston sampler Recommended piston sampler Recommended piston sampler
Sand	Moist	Loose	12	1/2	Poor	
Sand	Saturated	Dense	18 to 24	0	Poor	
Sand	Saturated	Loose	12 to 18	0	Poor	
Silt	Moist	Firm	18	1/2	Fair to good	Recommended piston sampler Recommended piston sampler
Silt	Moist	Soft	12 to 18	1/2	Fair	
Silt	Saturated	Firm	18 to 24	0	Fair to poor	
Silt	Saturated	Soft	12 to 18	0 to 1/2	Poor	
Clay and shale	Dry to Saturated	Hard				Recommended double-tube sampler
Clay	Moist	Firm	18	1/2 to 1	Good	
Clay	Moist	Soft	12 to 18	1	Fair to good	
Clay	Saturated	Firm	18 to 24	0 to 1	Good	
Clay	Saturated	Soft	18 to 24	1/2 to 1	Fair to poor	
Clay	Wet to Saturated	Expansive	18 to 24	1/2 to 1-1/2	Good	

1/ (U.S.B.R. Earth Manual, Tentative Edition with Revisions, 1951, 1953)

See Tables 4-1 and 4-2 for other types of samplers.

7. At the end of the drive the sampler is raised and the piston rod is disconnected by continuing to turn it clockwise until the rod is fully released. The piston is held in place at the top of its stroke by a split-cone clamp.
8. Before removing the sampler from the drilling mud at the ground surface, the hand or a block should be placed over the end to prevent the sample from dropping out.
9. Follow all instructions previously given for open-tube sampling.

#### Packaging of Sample

Wax and expanding packers are preferred for sealing the ends of the push-tubes or liners, however, they may be sealed with wooden plugs and wax. Care should be taken that no air space remains between the sample and the plug. Plugs should not be nailed in place in push tubes because the jarring required to drive the nails may disturb the sample. Tubes should not be crimped as is suggested for double-tube core barrel and split-tube liners. Labels and identification should be written on the tube or liner and not on the packers or plugs. Sealed samples should be packed completely surrounded with sawdust or excelsior to reduce vibration and shock. Two or more samples can be crated together for shipment but should not touch each other. Crates should be marked with precautionary signs such as: "Handle with Care", "this side up", "do not drop" and "protect from freezing."

#### Rotary Core Samples

##### Double-Tube Core Barrel Samples (Denison Type).

The most satisfactory attachment for obtaining undisturbed soil samples of tight cohesive materials is the double-tube core barrel with liner. This sampler is advanced by rotating the outer barrel which cuts a circular groove and loosens soil material to be displaced by the two barrels. Drilling fluid is forced downward through the drill stem between the two tubes and carries the cuttings to the surface outside the tubes and drill stem. The inner barrel advances downward over the undisturbed sample. A liner is fitted inside the inner barrel before the barrel is assembled. After drilling the required length the liner is removed and prepared for shipping (see page 5-12). Double-tube core barrels with liners come in various sizes, which obtain untrimmed soil samples ranging from 2-3/4" to 6" in diameter. Liners may be obtained in 9-inch lengths and 2-foot lengths. Seamless or rolled and welded liners are recommended for Service work with 9-inch sectional liners preferred.

Samples of cohesive soils are obtained with a Denison barrel with the least amount of disturbance possible and double-tube samplers can be used to sample a wide variety of materials. The method is not satisfactory for obtaining samples of soft, loose incoherent materials, especially below the water table.

### Single-Tube Rock Core Barrel Samples.

Single-tube core barrels are satisfactory for coring hard rock material. However, since the core is exposed to the drilling fluid over its entire length, the single-tube core barrel is not recommended for undisturbed samples of soils or weakly cemented, friable rocks.

### Double-Tube Rock Core Barrel Samples.

Double-tube rock core barrels are the most commonly used means of obtaining undisturbed cores of rock. Unlike the single-tube rock core barrel, this design has an inner tube or barrel which protects the core against the erosive action of the drilling fluid. The inner tube is usually attached to the core barrel head by a swivel head connection and therefore does not rotate during the coring, decreasing the amount of torsion exerted on the core by the rotating core bit and outer barrel.

### Sampling Procedures for Double-Tube Core Barrels.

**Soil Sampling.**--The basic principle of operation of the double-tube core barrel samplers is for the inner barrel to remain stationary (not rotate) and to slide over the sample which is cut by the rotating outer barrel.

The outer cutting bit, for soil sampling with double-tube core barrels, is made in several lengths so that the relation of the cutting edge of the inner barrel to the bit can be varied. A retracted inner barrel or long bit is used for very hard soils which are not subject to erosion. In dense or brittle soils a short bit is used so that the inner barrel is nearly flush with the cutting teeth. Soft, loose or slightly cohesive soils require the shortest bit and the maximum protrusion of the inner barrel so that the drilling mud does not wash out, penetrate, or undercut the sample. The sample should enter the barrel so that it fills the liner but the outer barrel should cut the core so that a minimum of downward pressure is required. The basic rules of operation are as follows:

1. Downward force should be a minimum; the downward force should be no greater than the speed at which the outer barrel is able to cut.
2. The speed of rotation should be limited to that which will not tear or break the sample.
3. The kind of cutting shoe and the extension of inner barrel should be adjusted to the soil being sampled.
4. The core retainer is a source of disturbance and should be eliminated if possible.
5. The consistency of the drilling mud should be governed by its purpose (see Chapter 4, table 4-3). The thinnest mud that will produce satisfactory results should be used.

6. Pump pressures should be the minimum required to carry the cuttings from the hole.
7. Total drive length should be a few inches short of the sample-container length.
8. Extreme care should be taken not to disturb the core during withdrawal from the hole and while removing the sample liner from the barrel.
9. Carefully remove all disturbed material from both ends of tube, paint with melted wax and package (see below).
10. Label liner (not ends) as instructed on page 5-10.

Rock Sampling.--The double-tube rock barrel differs from the soil-coring barrel in that it does not have a removable liner to hold the sample, and in the relationship of the cutting shoe to the inner shoe. The cutting shoe trims the core at slightly less diameter than that of the inner barrel and the sample is retained in the inner barrel by means of a core catcher. The basic rules of operation which apply to double-tube coring samples should be observed, where they apply, to rock coring.

In cases where there is a question as to the suitability of rock materials for a desired use, such as riprap, filter pack, roadways, or others, samples should be sent to the laboratory for special tests, such as freezing-thawing, wetting-drying (slaking), or rattler tests.

#### Packaging of Undisturbed Samples.

Samples collected with Denison-type core barrels with core drilling equipment are encased in metal liners when removed from the barrel. These samples should be plugged on both ends with expanding packers or wooden plugs secured with nails and the liner ends crimped.

Samples collected with drive samplers should be sealed in the tube with expansion packers. Samples collected by hand excavation can be placed in tin cans, Denison tins, or similar containers, providing they are tightly confined within the container.

All undisturbed samples should be thoroughly sealed with a high melting point wax. Beeswax or a mixture of beeswax and paraffin is recommended. Such wax does not shrink away from the container as badly as paraffin and usually has a higher melting point thus deforming less in hot weather. The wax seal should fill all voids between the sample and the container, as well as covering both ends of the sample. All undisturbed samples obtained from below the water table should be packed in excelsior, sawdust, or other shock-absorbent material and crated.

Where it is necessary to box and preserve rock cores for further study, they should be carefully handled and stored in boxes of dressed lumber or other suitable materials. Storage boxes should not be longer than necessary to adequately handle cores approximately four feet in length.

Not more than four cores should be stored in each box. Cores can be separated by longitudinal partitions and with separation blocks wherever core is lost. Embossed metal tape or other acceptable materials can be securely fastened in the box to indicate by elevations the beginning and ending of each reach of core in proper sequence as taken from boring. Cores should be placed first in a compartment next to a hinged cover proceeding towards front of box in the order cores are taken from the drill hole (as one reads a book). Elevations should also be noted on separation blocks on those reaches in which a core was unobtainable.

Storage boxes can be fitted with hinged or telescopic covers. The inside of the cover should be stenciled with the box number, project name, site number and hole number. Similar information should be stenciled on the outside of one end of the box.



## CHAPTER 6. DISTURBED SAMPLES

Purpose and Objectives

Disturbed samples are samples which lack their natural structure. To be adequate they must be representative of the strata, material, or area being sampled. Disturbed samples are usually obtained in three sizes: (1) Small samples weighing at least 4 pounds, (2) samples weighing a minimum of 25 pounds, and (3) large samples weighing 75 pounds.

Small disturbed samples are collected for determination of:

1. Classification and correlation.
2. Salinity, alkalinity and other chemical properties influencing behavior of soils.
3. Gradation.
4. Dispersion.
5. Atterberg limits.
6. Specific gravity.
7. Shrinkage limit.
8. Field moisture content.

Disturbed samples weighing at least 25 pounds are needed specifically for such laboratory determinations on remolded materials as:

1. Moisture-density relationship (compaction).
2. Shear strength.
3. Consolidation.
4. Permeability.
5. Reservoir sealing.
6. Special tests as required.

Disturbed samples weighing 75 pounds are needed for soil-cement tests. Where the larger disturbed samples are collected for shipment to the laboratory, small samples of the same strata are usually not necessary.

Preparation of Samples

Fragments larger than 3 inches in diameter (cobbles) should be removed from disturbed samples before shipment. A note on the Soil Sample List (see Figure 9-3) should explain what portion of the sample has been removed.

If more than 10 percent of the sample is larger than  $3/4$  inch, the laboratory screens out all material larger than  $1/4$  inch before making compaction tests. For mechanical analyses material larger than 2 mm is screened out. The sample should be large enough so that the amount of material under  $1/4$  inch remaining after screening will be at least 25 pounds. Thus, if the material being sampled is 50% gravel, a 50 pound sample is required.

Disturbed samples for moisture determination (split-tube samples) should be sealed immediately in wide mouth jars or plastic for shipment.

#### Methods of Obtaining Disturbed Samples

Representative disturbed samples are obtained by careful excavation by hand or, at greater depths, by bucket type augers or drive samplers. Care must be taken not to contaminate the sample with materials from strata other than one being sampled. Use of continuous flight augers and wash boring are unsatisfactory methods for obtaining samples of other than homogeneous materials. Proportionate volumes of all material between the selected elevations in the sample hole must be taken. If the sample so obtained is too large it may be reduced by quartering after thorough mixing.

Disturbed samples may be obtained with the split-tube sampler following the procedure given on pages 5-7 and 5-8.

#### Sample Containers

Disturbed samples should be placed in heavy canvas bags. Each State should maintain its own supply. When large numbers of samples are to be transmitted regularly from project areas, periodic return shipments of laundered bags will be made from the laboratory to one or more work areas in the state.

#### Availability.

Canvas bags are available, from U. S. Department of Justice, Federal Prison Industries, Inc., Washington 25, D. C. (f.o.b. Atlanta, Ga.). They are described as:

Item No. 24B-378-150, Bags, flat, 8 oz. Nat. duck, 6" x 10" at 13 cents each for samples up to 4 pounds.

Item No. 24B-378-400, Bags, flat, 8 oz. Nat. duck, 12" x 20" at 30 cents each for samples up to 25 pounds.

Large capacity bags (one bushel) may be obtained from General Services Administration, Federal Supply Service:

Item No. 8105-597-4757, Grain or Soil Bags. A strong open-end bag made of No. 12 natural duck with selvage top. No drawstrings, hem, or grommets, size 17" x 32", Standard pack: 200 -- 65 cents each.

## CHAPTER 7. LOGGING TEST HOLES

General

Logging is the recording of data concerning materials and conditions encountered in individual test holes. It is imperative that logging be accurate in order that the results can be properly evaluated to obtain a true concept of subsurface conditions. It is equally imperative that recorded data be concise and complete and presented in descriptive terms which are readily understood and evaluated in the field, laboratory, and design office.

Logging of materials is done on the basis of both the geologic and engineering properties of materials. The former is necessary for proper correlation and interpretation of geologic conditions of the site. This involves such considerations as age, origin, depth, thickness, continuity, attitude of strata and the nature of geologic features as folds, faults, joints, unconformities, etc.

The description of the engineering properties of materials is necessary for proper evaluation and interpretation for design and construction purposes. This involves such characteristics as gradation, permeability, plasticity, dry strength and toughness. Procedures for identification and classification of materials for engineering purposes follow the Unified Soil Classification System which has been adopted as standard by the Service (see "Engineering Classification of Soils", Engineering Memorandum No. 22, formerly Engineering Memorandum No. 14). Details of classification are outlined in Chapter 2.

Service procedure for logging includes, in general, field notes (figure 7-1), graphic presentation on SCS Forms 35A, 35B, and 35C, "Plan and Profiles for Geologic Investigations" and written logs on Form SCS-533. The graphic presentation facilitates geologic interpretation, and is best represented by geologic symbols. The written log is used primarily for design purposes and consequently materials are described in terms of their engineering and other properties. Both presentations are based on interpretation of field notes. Figures 7-2, 7-3, and 7-4, illustrate typical graphic logs of borings. In addition to the use of geologic symbols and notations for these logs, the Unified Soil Classification System letter symbol is used. The broken lines shown on figures 7-2, 7-3, and 7-4, represent correlation lines drawn by the geologist for interpretation purposes. Figure 7-5 illustrates a typical written log.

## Field Notes

September 23, 1958

Greentree Watershed, Olive Branch, Site 17

Intersection of Dam E and Principal Spillway, Hole 301.

Elev. 722.5

- 0.0-3.0 Silt, less than 10% sand (ML); slightly organic (grass and weed roots); moderate brown; low plasticity; low dry strength; rapid dilatancy; modern valley sediment, prob.: derived from loess. Hardness 1.
- 3.0-5.0 Silt, sandy (ML); sand is v. fine (20%); lt. brown. moderate dry strength due to slight  $\text{CaCO}_3$  cementation; occasional calc. concretions; vaguely stratified; quick reaction to shaking; non-plastic. Recent alluvium. Firm and fairly dense. Hardness 2. Moderate reddish brown.
- 5.0-9.0 Sand, gravelly (SW); well graded, 20% fine to coarse gravel; av. max. size 3"; about 10% silty, non-plastic fines. Gravel sub-rounded, granite and rhyolite w/ some purple quartzite. Wet; water table at 7.1'. Glacio-fluvial deposit. Permeable.
- 9.0-24.5 Clay, sandy and gravelly (CL-SC) plastic clay. High dry strength.  $\pm 25\%$  fine to coarse sub-angular quartz sand and sub-angular igneous gravel pebbles, av. max. diameter 3". Glacial till.

Firm and dense. Hardness 2. Oxidized to 20.0'; color moderate reddish brown; not oxidized below 20.0'; color medium bluish gray. Impermeable (appears unsaturated).

24.5-31.0 Sand, clayey (SC). Well graded; max. size about  $\frac{1}{16}$ "; non-plastic; moderate dry strength; moderately quick reaction to shaking. Stratified (water laid). Wet. Hardness 1, color - medium bluish gray. Moderately permeable. Occasional flecks of sericite.

31.0-38.5 clay, gravelly (CL) moderately plastic; high dry strength. About 15% coarse sand and igneous gravel up to  $\frac{3}{4}$ ". Glacial till. Hardness 2. Color - medium bluish gray (unoxidized). Impermeable.

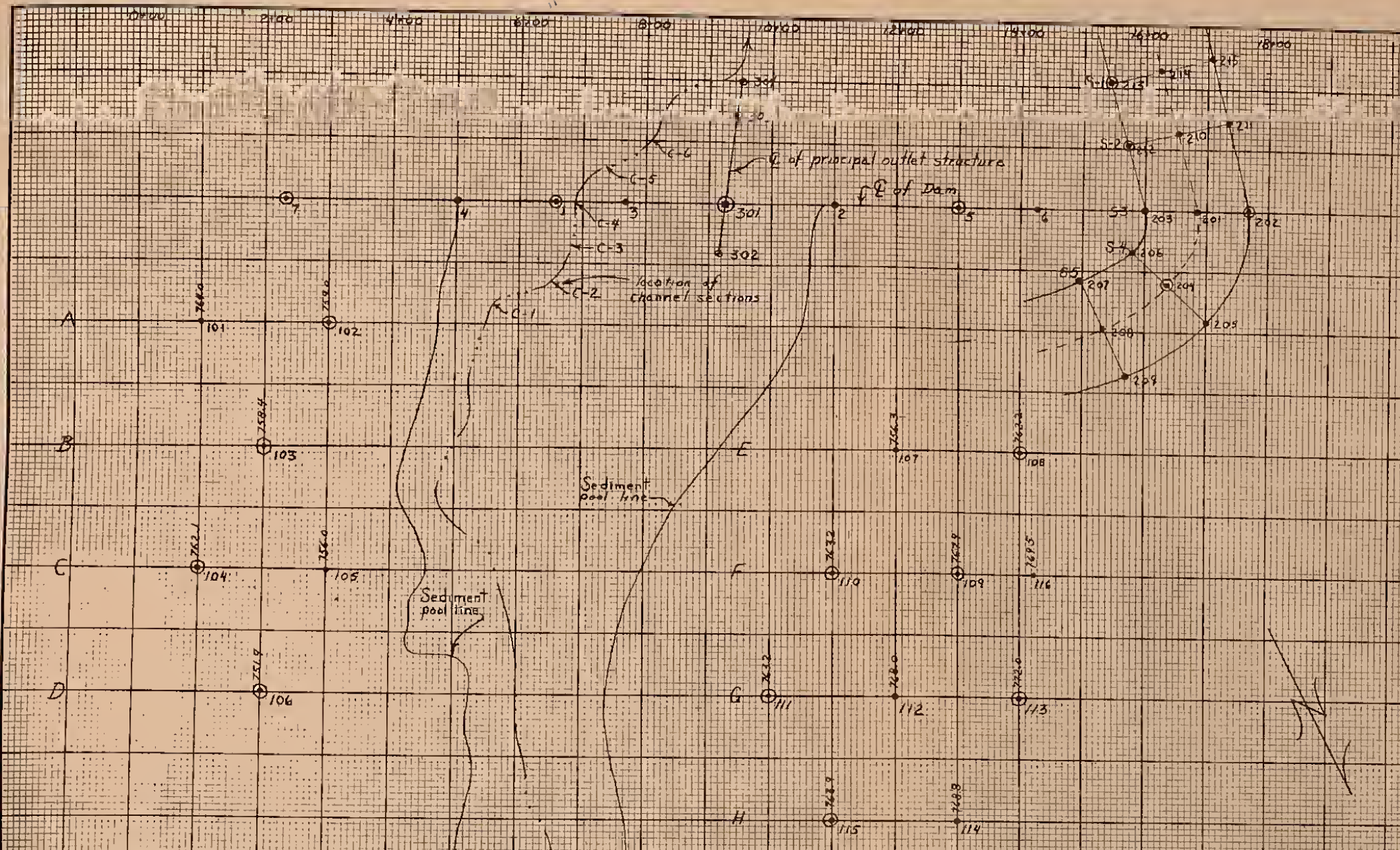
38.5-41.0 Sand, poorly graded (SP). Clean quartz sand; max. size about  $\frac{1}{16}$ ". Well rounded. Weathered Bear formation.

41.0-46.0 Bottomed in Bear Sandstone. Hard, medium grained cemented ss. Mississippian Age. Grains are well rounded, frosted and iron stained. Permeable. Hardness 5.

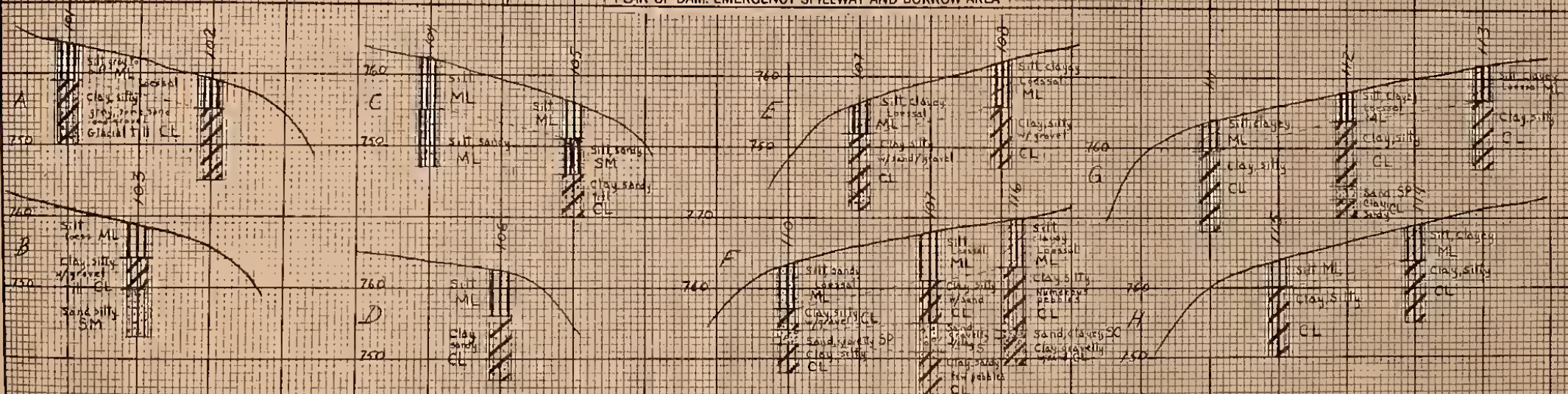
Total depth - 46.0'

Joseph Doaks





PLAN OF DAM, EMERGENCY SPILLWAY AND BORROW AREA



GEOLOGIC CROSS SECTIONS OF BORROW AREA

### LEGEND

#### SYMBOLS

##### UNCONSOLIDATED MATERIAL

gravel	sand	silt	clay	cobbles, boulders
gravel, sandy	sand, gravelly	silt, gravelly	clay, gravelly	peat
gravel, silty	sand, silty	silt, sandy	clay, sandy	expansive
gravel, clayey	sand, clayey	silt, clayey	clay, clayey	calcareous
gravel, sand, silt	sand, silt, clay	organic silt	organic clay	

\* To be added to Standard Symbol when significant amounts of dispersed gypsum or calcified zones are present in the section.

##### CONSOLIDATED MATERIAL

###### Sedimentary Rocks

shale	sandstone	limestone	chert	coal
calcareous shale	calcareous sandstone	cherty limestone	marl	gypsum
sandy shale	shaly sandstone	sandy limestone	chert	conglomerate
siltstone	breccia	dolomite		

###### Metamorphic Rocks

quartzite	slate	intrusive	extrusive
gneiss	schist	pyroclastic	
marble	soapstone	talc	serpentine

###### Undifferentiated

--	--	--	--

#### Other Symbols

○ hole logged only	↘ dip and strike
● hole sampled	○ pit or trench

#### ABBREVIATIONS

aq aquifer	tri triable
cav. cavities	lam laminated
Q centerline	mas massive
con concretions	ID total depth
US undisturbed samples	v. very
OS disturbed samples	w/ with
dip dipping	wea weathered
fract fractured	WL (date) groundwater level on a specified date

#### TEST HOLE NUMBERING SYSTEM

Centerline of dam	1 - 99
Borrow area	101 - 199
Emergency spillway	201 - 299
Centerline of outlet structure	301 - 399
Stream channel	401 - 499
Relief wells	501 - 599
	601 - 699
	701 - 799

#### UNIFIED SOIL CLASSIFICATION SYSTEM SYMBOLS

GW	Well graded gravels; gravel-sand mixtures
GP	Poorly graded gravels
GM	Silty gravels; gravel-sand-silt mixtures
GC	Clayey gravels; gravel-sand-clay mixtures
SW	Well graded sands; sand-gravel mixtures
SP	Poorly graded sands
SM-1	Silty coarse sand
SM-2	Silty fine sand
SC	Clayey sands; sand-clay mixtures
ML	Silt; silty, v. fine sands; sandy or clayey silts
CL-1	Clays of low plasticity; silty, sandy or gravelly clays
CL-2	Clays of medium plasticity; silty, sandy or gravelly clays
CH	Clays of high plasticity; lat clays
MH	Elastic silts; micaceous or diatomaceous silts
OL	Organic silts and organic silty clays of low plasticity
OH	Organic clays or silts of medium to high plasticity

### PLAN AND PROFILES FOR GEOLOGIC INVESTIGATIONS

Figure 7-2.

## Greentree Watershed

## Olive Branch Site 17

### U. S. DEPARTMENT OF AGRICULTURE

### SOIL CONSERVATION SERVICE

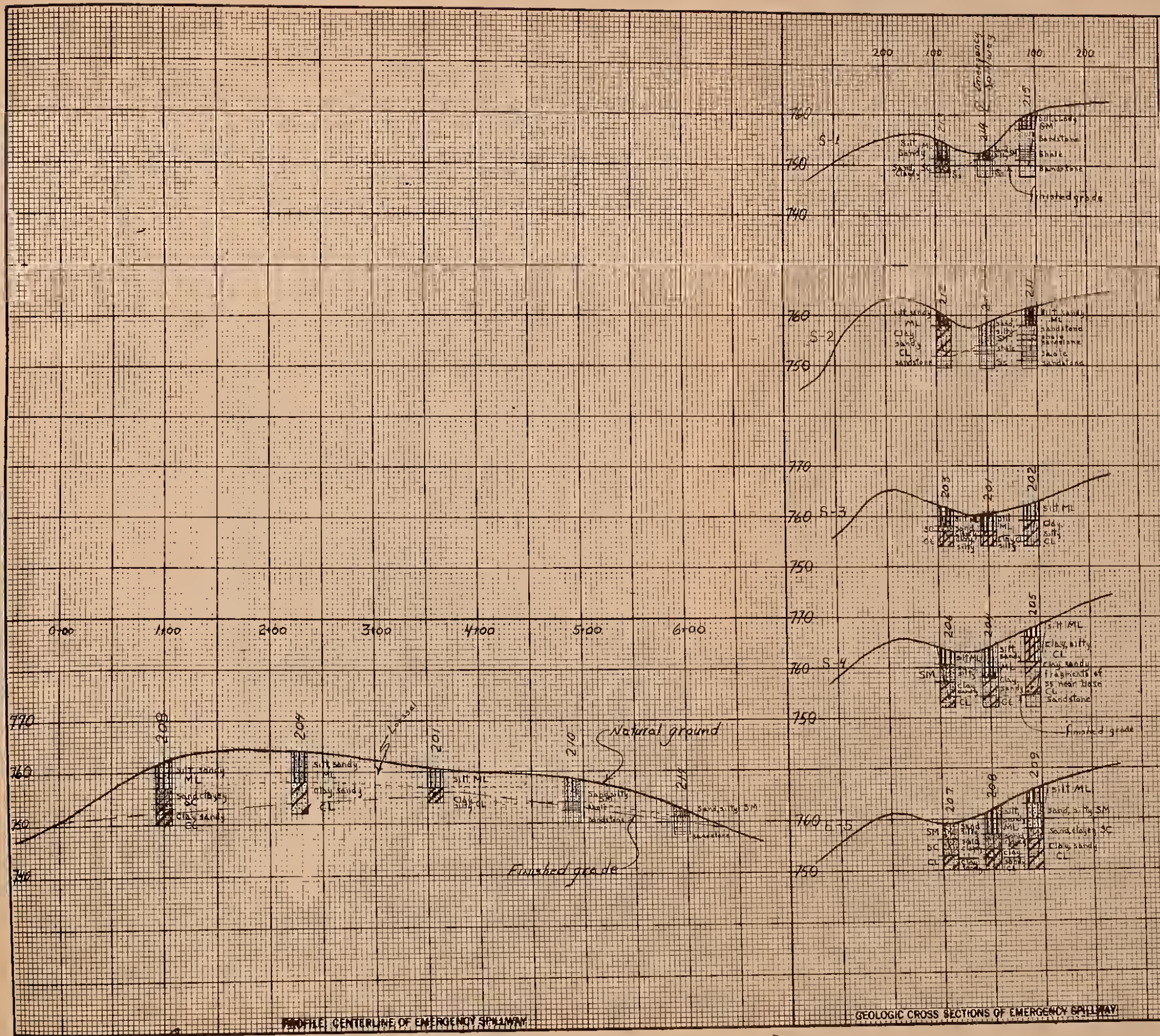
Investigated by	Date	Approved by	Date
John Deeks	8/1/64	John Deeks	8/1/64
Checked by	John Deeks	8/1/64	8/1/64
Title	Geologist	Sheet	Drawing No.
		1	

ES 900 Sheet 1 of 2 SCS-35A (April 1958)









### LEGEND SYMBOLS

#### UNCONSOLIDATED MATERIAL

gravel	sand	silt	clay	cobbles, boulders
gravel, sandy	sand, gravelly	silt, gravelly	clay, gravelly	peat
gravel, silty	sand, silty	silt, sandy	clay, sandy	gypsiferous
gravel, clayey	sand, clayey	silt, clayey	clay, silty	calcareous
gravel, sand, silt	sand, silt, clay	organic silt	organic clay	

\* To be added to Standard Symbol when significant amounts of dispersed gypsum or calcified zones are present in the section.

#### CONSOLIDATED MATERIAL

##### Sedimentary Rocks

shale	sandstone	limestone	chert	coal
calcareous shale	calcareous sandstone	cherty limestone	marl	gypsum
sandy shale	shaly sandstone	sandy limestone	chert	conglomerate
siltstone	breccia	dolomite		

##### Metamorphic Rocks

quartzite	slate	gneiss	schist	marble
		soapstone	talc	serpentine

##### Igneous Rocks

intrusive	extrusive
pyroclastic	

##### Other Symbols

hole logged only	dip and strike
hole sampled	pit or trench

#### ABBREVIATIONS

aq. aquifer	tri. triable
ccv. cavities	lam. laminated
cen. centerline	mas. massive
con. concretions	TD. total depth
US. undisturbed samples	v. very
OS. disturbed samples	w/ with
dip dipping	wea. weathered
frac. fractured	WL. (date) groundwater level on a specified date

#### TEST HOLE NUMBERING SYSTEM

Centerline of dam	1 - 99
Borrow area	101 - 199
Emergency spillway	201 - 299
Centerline of outlet structure	301 - 399
Stream channel	401 - 499
Relief wells	501 - 599
	601 - 699
	701 - 799

#### UNIFIED SOIL CLASSIFICATION SYSTEM SYMBOLS

GW	Well graded gravels; gravel-sand mixtures
GP	Poorly graded gravels
GM	Silty gravels; gravel-sand-silt mixtures
GC	Clayey gravels; gravel-sand-clay mixtures
SW	Well graded sands; sand-gravel mixtures
SP	Poorly graded sands
SM-1	Silty coarse sand
SM-2	Silty fine sand
SC	Clayey sands; sand-clay mixtures
ML	Silts; silty, v. fine sands; sandy or clayey silts
CL-1	Clays of low plasticity; silty, sandy or gravelly clays
CL-2	Clays of medium plasticity; silty, sandy or gravelly clays
CH	Clays of high plasticity; fat clays
MH	Elastic silts; micaceous or diatomaceous silts
OL	Organic silts and organic silty clays of low plasticity
OH	Organic clays or silts of medium to high plasticity

### PLAN AND PROFILES FOR GEOLOGIC INVESTIGATIONS

Figure 7-4.

## Greentree Watershed

## Olive Branch Site 17

### U. S. DEPARTMENT OF AGRICULTURE

### SOIL CONSERVATION SERVICE

Investigated by <b>Joseph Doaks</b>	Date <b>9/17/61</b>	Approved by _____
Title <b>Geologist</b>		Title _____
Checked by <b>John Adams</b>	Date <b>9/18/61</b>	Approved by _____
Title <b>Geologist</b>		Title _____

Sheet No. \_\_\_\_\_ of \_\_\_\_\_

Drawing No. \_\_\_\_\_

ES 900 Sheet 3 of 3 SC3-75C (April 1958)



## LOG OF TEST HOLES

U. S. DEPARTMENT OF AGRICULTURE  
SOIL CONSERVATION SERVICE

Location 5 miles S. E. of Watertown Owner Greentree State Any state Site No. 17  
 Watershed Greentree Sub-watershed Olive Branch  
 Logged by Joseph Doebs Date 9/23 19 92 Project: WP1 X WP2    FP    Pub. 46  
 Drilling Equipment Core drill Location of Holes Centerline of principal spillway

Hole No.	Station and Surface Elev.	Hole Depth		Description of Materials.	Unif. Soil Class. Symb.	Type Bit Used	Samples			
		From Ft.	To Ft.				No.	Type	From Ft.	To Rec. %
301	9+25	0.0	3.0	Silt, little clay or sand; slightly organic; low plasticity; hardness 1; modern valley sed. derived from loess.	ML	P.T.	1	D	0.0	3.0
	722.5									
		3.0	5.0	Silt, sandy; 20% very fine sand; moderate dry strength due to slight calcareous cementation; non-plastic	ML	P.T.	2	D	3.0	5.0
				recent alluvium; firm; fairly dense; hardness 2.						
		5.0	9.0	Sand, gravelly; well graded; 20% gravel-3/4 inch av. max. size. water table at 7.1: permeable.	SW	Aug.	3	D	5.0	9.0
		9.0	24.5	Clay, sandy and gravelly; plastic clay. high dry strength; 45-50% igneous gravel (max. 3 in.) sub-angular, and fine to coarse sand; hardness 2; glacial till, oxidized to 20 ft.; impermeable (appears unsaturated).	CL-GC	Aug.	9	U	15.0	17.0
		24.5	31.0	Sand, clayey; well graded; max. size 1/16 in.; non-plastic stratified; moderately permeable; saturated; hardness 1.	SC	P.T.	10	U*	26.0	28.0
		31.0	38.5	Clay, gravelly; moderately plastic; high dry strength; about 15% coarse sand and igneous gravel - 3/4 in. max. size; glacial till; impermeable; hardness 2.	CL	P.T.	7	D	28.5	30.5
				Sand; poorly graded; clean; well rounded; 1/16 in. max. size; weathered sandstone.			11	U*	33.0	35.0
		38.5	41.0	Sandstone; hard, cemented, permeable. Bear formation	SP	P.T.	8	D	39.0	40.5
		41.0	46.0	Disturbed, undisturbed-rock core. † Percent sample recovery. 1 copy to E and WP Unit, 1 copy Soil Mechanics Laboratory with samples. Other copies as directed by State Conservationist.						

Sheet 1 of 1 Sheets

T.D. = 46

\* Undisturbed samples taken from an offset hole

Figure 7-5

## Field Notes

### Preparation of Field Notes.

The geologist logging a test hole may keep field notes in a separate notebook or use Form SCS-533. Field notes may contain considerably more information than normally would be included in either graphic or written logs. The preparation of field notes should include the important geologic and physical features of the materials and such engineering properties that can readily be determined visually and manually. The field notes provide the basis for developing graphic and written logs. Descriptive material for each hole should be recorded in field notes in approximately the following order:

1. Hole number and surface elevation.--Holes should be numbered according to their location (See Chapter 9), record depth to upper and lower limits of strata being described.
2. Texture.--In unconsolidated materials the primary constituent (gravel, sand, silt or clay) is mentioned first, followed by a modifier if necessary, e.g., sand, silty. Shapes, size, and approximate percentage composition of the coarse-grained components should follow. Gradation of particles and characteristics of individual particles (platy, diatomaceous, etc.). For consolidated rocks, the lithology of each unit should be described in terms of the dominant rock type (granite, sandstone, shale, etc.); texture, (coarse, medium or fine-grained); gradation; particle shape and roundness; color of the fresh surface; and mineralogy of the detrital particles and cement.
3. Color and consistency or hardness.--The color in place should be recorded for correlation purposes. Rock hardness is essentially comparable to degree of cementation and compaction. Unconfined compressive strength is related to soil consistency which is influenced by such factors as moisture content and degree of compaction. The hardness scale presented in Chapter 2 may be used to describe hardness of the materials.
4. Permeability.--Field estimates of relative permeability should be recorded using terms such as highly, moderately, slightly permeable, or impermeable.
5. Other characteristics.--Pertinent characteristics, such as odor; cavities; fractures; jointing; wetness; degree of oxidation; strike and dip; and genetic name (e.g., alluvium; loess); and origin, degree and nature of cementation; presence of materials such as calcium carbonate, calcium sulphate, coating of particles; iron; etc., should be recorded. Formation or member names, together with geologic age, if known, are also helpful in interpretations. Simple identification of fossils, artifacts, etc., if practical, should be made to aid in correlation.

6. Mechanical information.--Drilling difficulties and core or sample losses and the reason therefore should be recorded on log. Thus, resistance to advance of hole, loss of drilling fluid, penetration resistance, and sample recovery ratio are factors which aid in interpretation of character of materials.
7. Water levels.--The static water level on a given date, or dates should be recorded. A rise in water level as drilling proceeds is indicative of the presence of artesian aquifers.

### Graphic Logs

It is necessary that the graphic logs, which provide the basis for planning the location and depths of subsequent borings, be kept current with field notes during the investigation. By the same token correlation lines must be kept current so that questionable correlations can be resolved without excessive drilling.

#### Forms 35A, 35B, and 35C.

Individual graphic columns, (see Figures 7-2, 7-3, and 7-4) are to be shown on Forms 35A, 35B, and 35C "Plan and Profiles for Geologic Investigation" in their proper location and depth for correlation purposes. The columns will be prepared using the patterns contained in the Standard Geologic Symbols as shown in the legend of the form. A "tick mark" is to be used to show the location of major changes in strata. It is important that graphic logs be plotted to scale and properly referenced to elevation. Mean sea level is to be used, if possible, or assumed datum if MSL is not available. In this respect graphic columns which may be off the centerline profile may show as being above or below ground level of the profile, depending on the ground elevation of the boring. In this event, a notation is to be made at the top of the column showing location in respect to centerline of the profile.

The location of the static water table, if encountered, is to be indicated at the proper elevation along with the date of measurement. The Unified Soil Classification System symbol is to be shown adjacent to each stratum shown on the graphic column as a further guide to interpretation and sample requirements. In addition, other salient features of the strata will be shown using adjectives and abbreviations of adjectives shown in the legend, for example: Wet, hard, mas. (massive), etc. The holes will be properly numbered according to their location on both plans and profiles. On plans the location of holes will be designated by the proper symbol indicating whether the hole was sampled or not.

The graphic log should be plotted on field working sheets of Forms 35A, 35B, and 35C, as soon as drilling of a particular hole has been completed. Correlation lines should be drawn in as soon as they can be developed so that additional borings may be properly planned in accordance with needs. Once the continuity, thickness, extent, and other

characteristics of strata at the site have been determined (correlation established) follow-up borings can then be made to obtain undisturbed samples of questionable materials for laboratory analysis. The graphic logs provide a guide to selection of location and depth at which undisturbed samples are to be obtained.

### Distribution of Logs, Plans and Profiles

When the field working sheet has served its purpose it is reproduced for distribution. Reproduction of rough field sheets can be accomplished by blue-line print or photostat locally in the field or in the Cartographic Unit. A copy of the field sheet is needed immediately by the soil mechanics laboratory, if samples are sent, and by the geologist for completing his report. Final drafting of field sheets is to be done by the Cartographic Unit serving the State. Lumarith stickups of standard geologic symbols have been prepared and stocked by the various Cartographic Units to facilitate drafting of plans and profiles. Copies of final logs, plans, and profiles are to be attached to the geologic report for submission to the EWP Unit geologist, the soil mechanics laboratory for all sites for which samples are submitted and accompanying the design data sent to the EWP Unit. Requirements for distribution of reports are stated in Engineering Memorandum No. 33.

### Written Logs

#### Form SCS-533

Written logs for engineering purposes are recorded on Form SCS-533, "Log of Test Holes". These are developed from field notes and are restricted to those items directly applicable to engineering considerations. The detailed logs are developed using common narrative descriptions of the material in terms which are readily understandable. The order of listing specific items should be consistent with that described under "Field Notes". A typical written log for unconsolidated and consolidated material is shown in Figure 7-5.

The first column of Form SCS-533 provides space for designation of the hole number. The second column is used to designate the location and surface elevation. Each log should show hole number, location, and surface elevation. Several logs may be shown on each sheet of Form SCS-533. Therefore, the designations in these columns distinguish the different borings and logs.

The third column "Hole Depth" includes the depth in feet from the surface (0) to the bottom of the first strata, or from the top to the bottom of any strata as the case may be.

Description of materials should be complete, clear and concise. The first term in the description should be of the geologic designation of the material corresponding to the standard pattern used on the graphic log, this is to be underlined, for example: Gravel, silty. The character of individual particles, where identifiable by eye is then presented in terms of size, shape and composition. This includes the approximate diameter of the average maximum size particle. Where possible, the relative percent

of gravel, sand, silt, and clays should be indicated. Particle shapes are described in such terms as angular, sub-angular, rounded, etc. The principal constituents of the larger particles, such as metamorphic, limestone, granite, sandstone, etc., should be noted. Presence of platy minerals (such as micas), diatoms, caliche, gypsum, iron stains, organic matter, etc., which have an influence on the engineering properties should be noted. The color and consistency or hardness should be recorded. For fine-grained soils, the relative plasticity, dry strength and toughness should be noted. The relative position of stratification should be indicated: For example "varved clay", "inter-bedded sand and gravel". Presence of joints; indicating kinds, spacing, and strike, if determinable. The consistency of cohesive materials should be indicated. Wherever possible, define the genesis such as alluvium, lacustrine, till, residual, etc.

Form SCS-533 is also used for written logs of consolidated rock. The kind of rock, weathering characteristics, cementation, fractures, fissures, strike and dip, structural and other features, should be included in the description. The geologic name and age of the formation, if known, should be included. It is also important to describe the ease of excavation using the scale of hardness.

The Unified Soil Classification symbol based on field tests goes in column 5.

Column 6 of Form SCS-533 should be used to describe the type and size of bit used for advancing hole. Examples would be flight auger, bucket auger, push tube, stationary piston tube, double-tube core barrel, single-tube diamond core barrel, etc.

Columns 7, 8, 9, and 10, apply to sample data. It is important to show the sampling horizon and whether or not the sample is "disturbed"(D), "undisturbed"(U), "rock core"(R). The sample recovery ratio (S) which is equal to  $L/H$  where L is the length of sample recovered and H is the length of penetration is to be shown as a percent ratio. Thus, if the sampler penetrated a distance of 18 inches and sample contained therein amounted to 16 inches  $(S) = \frac{16}{18} \times 100 = 89\%$ . This may be an important

factor in respect to the determination of fissures or cavities in consolidated rock, or may be an indication of soft, interbedded material between layers of hard consolidated rock.

#### Distribution of Written Logs

Distribution of completed written logs will be the same as that for graphic logs. Copies of written logs can be typed with sufficient carbon copies to supply needs for distribution. There is no requirement in respect to destination of the ribbon copy versus carbon copies. Normally the ribbon copy of the geologic report and written logs would accompany the design data sent to the EWP Unit.



## CHAPTER 8. PRELIMINARY GEOLOGIC EXAMINATION

General

A preliminary dam site investigation is made by the geologist soon after the tentative selection of the site and should include a review of all available literature and maps relating to the regional geology and physiography. In P.L. 566 projects, this investigation is usually made in the work plan stage. Studies should be made of surface outcrops, channel sections, groundwater conditions, and approximate depth of alluvium in the floodplain. Faults, weak bedding planes, joint systems, and very erodible or unstable materials which appear at the surface should be located.

The preliminary examination is made to determine what geologic problems and resultant difficulties are likely to be encountered in construction. The data are used to obtain more accurate construction cost estimates, based upon the site difficulties anticipated, such as high-water table, rock excavation, or need for relief wells, foundation drains, or flatter side slopes on dams. Such factors may greatly increase the cost of dams and seriously affect the benefit-cost ratio of proposed watershed projects.

The investigation is primarily a study of surface geology from outcrops, streambanks, geomorphology, etc., but may be supplemented by power equipment if warranted. The detail of the examination is governed by the critical problems encountered.

Assembly of DataMaps, Reports, and other Information.

The primary purpose of a preliminary geologic site investigation is to determine whether the site appears feasible from a geologic standpoint including adequacy of available borrow material, and to determine the kinds and extent of detailed investigations needed for the development of final design data for the proposed structure.

Before beginning a field study of a site the available geological, physiographic and engineering experience data should be reviewed. The usual sources of reference data are publications of the U. S. Geological Survey, state geological surveys, U. S. Department of Agriculture Soil Survey Reports, special reports and papers in scientific publications and Federal, state or local engineering experience information if available. In addition, a base map on a usable scale, topographic sheets, aerial photographs, and geologic and soils maps are helpful. Preliminary information on the location of the proposed dams is essential. The following site information will prove useful for preliminary site investigations:

1. Location and purpose of dam and reservoir.
2. Estimates of height of dam and cubic yards of compacted fill required.

3. Estimated maximum and normal pool elevations.
4. Class of structure in accordance with Engineering Memorandum No. 27.
5. Approximate area in reservoir basin.
6. Approximate spillway location.
7. Approximate location of outlet structures.

The importance of studying aerial photographs of the general area of the site should not be overlooked. Stereoscopic prints are best suited for this purpose. Tone, texture, land forms, etc., often are indicators of geologic conditions including boundaries of soil and rock materials, faults, fractures, sinks, landslides, moisture, etc. Studies of stereoscopic prints provide the geologist with a mental, three-dimensional, picture of land forms as a guide to establishing the general geology subsequent to field checking. Geologic and topographic maps are essential for determining the general geology and soils maps are helpful for general delineation of boundaries of particular types of surface materials.

Wherever possible, the geologist should take advantage of the general design and construction experience and the performance of existing structures in the area. Interviews with engineers or other technicians familiar with design and operation of the structures and visits to structures under construction in the field would be particularly helpful in areas where the geologist has had little or no experience. Existing reports on laboratory analyses to determine physical and engineering properties should be reviewed for possible application to the site in question.

There should be a mutual understanding and close cooperation between the geologist and the designated engineer during the period of preliminary site examination. Special problems arising from geologic conditions which may require relocation of the principal or emergency spillway, or other alterations of design to fit the site, should be discussed in the field by the geologist and engineer and a plan of investigation developed. This procedure should be followed whether the work is to be done by a Service drilling party or a drilling contractor is employed.

#### Field Investigations

A study of the site should include a brief traverse of the valley for approximately a mile above and below the site. This should include a study of slopes, tributary valleys, landslides, springs and seeps, exposed rock sections, and the nature of unconsolidated overburden such as glacial drift or loess to obtain information on the general geology of the area. A brief inspection of the upland and valley slopes will provide clues as to the thickness and sequence of formations and rock structure. The examination of the valley should include inspections of the shape and character of channels and the nature of residual, colluvial, alluvial, fan, slide or other types of deposits. Any observations that can be made of groundwater occurrence, especially in alluvial deposits, should be

recorded. Possible sources and approximate amounts of borrow and core material should be noted. A few hand-auger borings or test pits may be needed to complete the preliminary examination.

The geologist should make a thorough inspection of the dam and reservoir area. He should identify and describe all geologic formations visible at the surface and note their topographic positions. He should determine the local dip and strike of the formations, keeping in mind that a gentle dip downstream may cause leakage along bedding planes, and even sliding of the dam in the case of weak shale or clay layers. A strike parallel to the valley, with moderate to steep dip, also may result in seepage. A dip upstream usually provides a safe foundation.

The geologist should locate and delineate any faults visible on the surface. Faults and fault zones may cause serious leakage, and when they become wet, movement along the fault may take place, resulting in differential settlement. When faults are numerous, active, or of large displacement they may require relocation of the dam or the principal spillway.

If there is doubt as to whether the site is feasible from a geologic standpoint, the geologist should consult immediately with the designated engineer and advise the State Office of the situation. The State Office may request further technical assistance from the Engineering and Watershed Planning Unit.

Hand-auger borings or test pits may be needed for some preliminary exploration at the dam site, or, if power tools are available, they should be used if conditions warrant. If any geologic conditions which might preclude the use of a dam site appear to be present they should be investigated in the preliminary examination.

Depths to ground water, depths to bed rock, thickness of recent alluvium and colluvium and availability of suitable borrow material may require some subsurface exploration.

### Mapping

Where the geology is complicated, it is advisable to prepare a geologic map of the site. The best available base map or aerial photograph should be used for this purpose. Plane-table surveys may be required. Features which might appear on the map include:

1. Areal geology of all surface formations within the area being mapped, including delineation of unconsolidated deposits.
2. Texture of surficial deposits.
3. Structure of bedrock, including dip and strike, faults or fractures, stratification, porosity and permeability, schistosity, and weathered zones.

4. Groundwater features, including seeps, springs, observable water tables, and drainage.
5. Areas of accelerated deposition.
6. Unstable slopes, slips, and landslides.

#### Report of Preliminary Examination

Form SCS- "Preliminary Geologic Examination of Dam Sites" (Figure 8-1) may be used for reporting on each dam site examined by a geologist. The log of test holes, Form SCS-533, (Figure 7-5) is used to record information from any power drilling, test pits, or hand augering. One copy each of Form SCS- (Figure 8-1) and SCS-533 should be furnished to the EWP Unit Engineering Geologist. This information is useful in planning a detailed subsurface investigation if such is necessary. Form SCS- (Figure 8-1) is for in-Service use only and should be restricted to Service personnel.

In some instances the preliminary site examination, together with knowledge of and experience in the area provide sufficient information for design without further detailed investigation. This may be true for small structures on less complex sites, or on generally homogeneous sites where experience from previous investigations on similar sites is considered to be adequate for the site (See Chapter 3). In such cases Forms SCS-35A, 35B and 35C should be prepared from the hand-auger data and be submitted with the report. Where samples from sites having similar conditions have been analyzed and used as criteria in preparing recommendations, the report should contain a reference to these samples and availability of results.

Where a preliminary site examination is insufficient to provide the knowledge and stratigraphy of a site to the extent required for design and construction, or, where such knowledge is adequate (from auger borings) but samples for laboratory analysis could not be obtained with available equipment, a subsequent detailed subsurface investigation would be recommended in the report.

In those instances where previous knowledge permits a preliminary examination to be used for design purposes it will be necessary to adequately locate and delineate areas for borrow purposes. This can be done only by subsurface exploration. Therefore, it is required that detailed investigation of the borrow areas, as described in Chapter 9, be performed in all cases.

U. S. DEPARTMENT OF AGRICULTURE  
SOIL CONSERVATION SERVICE

PRELIMINARY GEOLOGIC EXAMINATION OF DAM SITES

State \_\_\_\_\_ County \_\_\_\_\_ Watershed \_\_\_\_\_, Site No. \_\_\_\_\_

Subwatershed \_\_\_\_\_, Drainage Area: acres \_\_\_\_\_, sq. mi. \_\_\_\_\_

Date \_\_\_\_\_, Investigated by \_\_\_\_\_

(Signature of Geologist)

Type of Construction: Concrete \_\_\_\_\_ Rock Fill \_\_\_\_\_ Zoned \_\_\_\_\_ Homogeneous \_\_\_\_\_

Purpose of Structure \_\_\_\_\_

Length of Embankment \_\_\_\_\_ ft., Height \_\_\_\_\_ ft., Cubic Yards \_\_\_\_\_

Direction of Streamflow \_\_\_\_\_

Hazard class \_\_\_\_\_ Site Group \_\_\_\_\_

Fund Classification \_\_\_\_\_

FP-2, WP-1, etc.

General Geology

Physiographic Area \_\_\_\_\_

Steepness of Abutments: (looking downstream) Left \_\_\_\_\_ percent, Right \_\_\_\_\_ percent

Geologic Formations \_\_\_\_\_

Direction and Percent Dip \_\_\_\_\_

Surficial Deposits (describe briefly) \_\_\_\_\_

Faults, Joints, Springs, Caverns and Slide Areas (describe briefly) \_\_\_\_\_

Foundation

Geologic Description \_\_\_\_\_

Depth to Rock Min. Max. Avg. Depth to Ground Water \_\_\_\_\_

Type of Rock \_\_\_\_\_

Leakage Problems \_\_\_\_\_

Treatment Suggested: Toe Drains \_\_\_\_\_ Relief Wells \_\_\_\_\_ Blanket \_\_\_\_\_ Grouting \_\_\_\_\_

Example of Report Form SCS- \_\_\_\_\_ for Preliminary Geologic Examination

## PRELIMINARY GEOLOGIC EXAMINATION OF DAM SITES (Cont'd.)

Emergency Spillway

Best Location: Left Abutment \_\_\_\_\_ Right Abutment \_\_\_\_\_ Other \_\_\_\_\_

Type of Material in Cut \_\_\_\_\_ Volume \_\_\_\_\_

Is Material Suitable for Fill? \_\_\_\_\_ What Type? \_\_\_\_\_

Probable Rock Excavation: Type \_\_\_\_\_ Amount: High \_\_\_\_\_ Medium \_\_\_\_\_ Low \_\_\_\_\_ None \_\_\_\_\_

Erodibility: Control Section: High \_\_\_\_\_ Medium \_\_\_\_\_ Low \_\_\_\_\_  
 Exit Channel: High \_\_\_\_\_ Medium \_\_\_\_\_ Low \_\_\_\_\_

Outlet Channel

Description: Width \_\_\_\_\_ Depth \_\_\_\_\_ Type of Bottom Material \_\_\_\_\_

Size of Bed Material (d<sub>75</sub>) \_\_\_\_\_ ft. \_\_\_\_\_ ft. inches, Scouring \_\_\_\_\_ Aggrading \_\_\_\_\_

Present Condition of Banks: Eroding \_\_\_\_\_ Fair \_\_\_\_\_ Stable \_\_\_\_\_

Borrow Areas

Location \_\_\_\_\_, Probable Depth \_\_\_\_\_, Area \_\_\_\_\_, Cu.Yds. \_\_\_\_\_

Description of Materials \_\_\_\_\_

Depth to Water \_\_\_\_\_ Are Salts or Dispersed Soils Present? \_\_\_\_\_

Location \_\_\_\_\_, Probable Depth \_\_\_\_\_, Area \_\_\_\_\_, Cu.Yds. \_\_\_\_\_

Description of Materials \_\_\_\_\_

Depth to Water \_\_\_\_\_ Are Salts or Dispersed Soils Present? \_\_\_\_\_

Location \_\_\_\_\_, Probable Depth \_\_\_\_\_, Area \_\_\_\_\_, Cu.Yds. \_\_\_\_\_

Description of Materials \_\_\_\_\_

Depth to Water \_\_\_\_\_ Are Salts or Dispersed Soils Present? \_\_\_\_\_

Miscellaneous

This investigation was made by: Power drilling equipment \_\_\_\_\_

Test Pits \_\_\_\_\_ Hand auger \_\_\_\_\_ Inspection of surface \_\_\_\_\_

Is Detailed Subsurface Investigation Recommended? \_\_\_\_\_

PRELIMINARY GEOLOGIC EXAMINATION OF DAM SITES (Cont'd.)

If so, Why? (explain briefly) \_\_\_\_\_

\_\_\_\_\_

Type of Equipment Required for Detailed Geologic Investigation \_\_\_\_\_

State Reasons \_\_\_\_\_

Intensity of required detailed investigation \_\_\_\_\_

\_\_\_\_\_

Interpretations, Conclusions, and Suggestions

Interpretations: (Describe general geology of the site):

Conclusions: (Describe geologic conditions which require special considerations in design and constructions):

## PRELIMINARY GEOLOGIC EXAMINATION OF DAM SITES (Cont'd.)

Suggestions: (Outline briefly suggestions which might be considered in design and construction for solution of specific geologic conditions):

---

(Signature of Geologist)

## CHAPTER 9. DETAILED GEOLOGIC INVESTIGATION

General

Subsurface investigations of dam sites are made following a study of the surface geology. The nature and intensity of the underground exploratory work for a particular type and purpose of structure is conditioned by this prior examination of the area. As the subsurface work progresses, the findings may further modify the required intensity of investigation. The intensity of investigation, all other conditions being equal, is dependent upon complexity of the site.

Detailed subsurface investigations may be carried out by contracting with local companies or by use of Service personnel and Service-owned equipment.

Contracting for Site InvestigationsGeneral.

In those states where the present annual work load is not sufficient to justify the purchase of drilling equipment, core-drilling services must be obtained for subsurface investigations by contracting with private companies. Such services may be obtained by: (1) Equipment rental contract let by the Service, or (2) inclusion in a Service-negotiated engineering contract for professional services (See Engineering Memorandum SCS-36). When an equipment rental contract is let, logging and classifying materials as well as developing interpretations and preparing the reports are the responsibility of Service personnel, the only variation in regular procedures being that the contractor provides and operates the equipment. In the negotiated engineering contract, the contractor is required to provide and operate exploration equipment, log and classify the materials, and prepare the geologic report. A negotiated engineering contract may be let for site investigation alone, or, as part of an overall contract including laboratory analysis and development of final design.

Minimum requirements and technical standards for Service work are the same for contracted work as for work done with Service-owned and operated equipment. The successful completion of a contract for site investigations depends primarily upon: (1) the efficiency of planning, (2) development of suitable specifications, (3) supervision provided during the investigation, and (4) competency of the drilling contractor. The following provides guidelines in respect to technical phases of contract development for site investigations.

Planning.

The development of suitable specifications requires prior knowledge of the general geology of the area and specific conditions at the site. Consequently, a preliminary site examination and assembly of basic data are necessary for contract drilling in the same manner as for Service drilling. The following step-by-step procedure is suggested for obtaining preliminary data for preparation of specifications for contracting on an equipment rental basis:

Step 1. Assemble available aerial photographs, maps, reports and other data pertaining to general area of site.

Step 2. Map geology at the area as accurately as possible, noting conditions that require subsurface investigation.

Step 3. Make estimates of the number and depth of test holes required to map subsurface conditions and solve foundation problems.

Step 4. Develop general test hole program so that it will be directed to solve definite geologic problems that will affect design and construction of the dam, such as

- a. Depth and nature of alluvium and other unconsolidated materials.
- b. Depth to water.
- c. Condition of rock.

Step 5. Review results of preliminary geologic examination with engineers to determine requirements for design and construction.

Step 6. Develop plan of operations for the investigation program. Establish location of the first test hole and make each additional test hole a step in solving foundation problems.

Step 7. Locate tentative test holes on a plan or map at the site.

Step 8. Estimate depth of each tentative test hole and total footage for each type of test hole or method of boring.

Step 9. Determine approximate number and method of obtaining undisturbed and disturbed samples.

Step 10. Estimate approximate number of hours for drilling and sampling time, including moving time between holes (and sites if more than one is involved in contract) to arrive at an overall time estimate for length of contract and estimated cost.

Step 11. Canvass the area within a reasonable travel distance of the work to become informed on the available contractors.

Step 12. Supply the Administrative Officer with time estimates and other information needed to develop the contract. This will involve such items as:

- a. Footage and types of borings.
- b. Number and kinds of samples.
- c. Equipment and tools necessary to perform work.

- d. Time for executing each operation.
- e. Time for completion of contract.
- f. Summary of estimated cost for hourly rental of equipment and operators.
- g. Mobilization cost to and from site.
- h. List of competent, prospective bidders.

#### Development of Specifications for Equipment Rental Contracts.

Development of contracts is done by the contracting officer. The general information contained in contracts follows a more or less standard pattern with the exception of the detailed specifications needed to successfully complete the work. Since development of specifications involves technical considerations, geologists can provide valuable assistance to the contracting officer. The descriptions of equipment, tools, methods and procedures contained throughout "Guide to Geologic Investigations of Dam Sites" provide a basis for development of these specifications. The following general considerations need to be observed in developing certain aspects of the specifications:

- a. Specifications should be flexible to the extent that the number, depth or location of test holes may be changed at any time by the Government Representative as the investigation proceeds.
- b. The contract should not be limiting in respect to the number and kinds of samples to be obtained since these items are determined on basis of conditions actually encountered at the site as the work proceeds.
- c. Special procedures and methodology for advancing test holes, sampling and conducting special tests should be spelled out in sufficient detail to assure conformance with Service standards.
- d. Specifications must conform to Service policy.

#### Development of Specifications for Negotiated Engineering Contract.

Responsibility for carrying out the terms and conditions of the contract and the preparation of the final report of findings rests with the contractor in the negotiated engineering type of contract. In the preparation of specifications for this type of contract, it is required that the completed work conform with Service standards. Since "Guide to Geologic Investigations of Dam Sites" sets forth minimum requirements and establishes standards for Service geologic site investigations, this document can be used as supporting material for developing specifications to assure conformance with Service requirements and standards.

#### Supervision of Site Investigations.

Supervision of site investigations on an equipment rental type of contract is provided by the Government Representative. Selection of the

Government Representative should be based on complexity of site conditions and intensity of site investigation needed to satisfy minimum requirements. Therefore, a geologist should serve as Government Representative on contracts involving Group I and Group III sites (see Chapter 3). In order to properly supervise site investigations the Government Representative must be familiar with:

- a. Geologic problems as they affect the design and construction of a dam.
- b. Drilling equipment and its operation.
- c. Procedures for logging and development of stratigraphy.
- d. Requirements and procedures for obtaining disturbed and undisturbed samples.
- e. Geologic report preparation.
- f. Administration of contracts.

No technical supervision is provided for negotiated engineering contracts. However, every effort should be made to advise the contractor of Service requirements and acceptable standards.

#### Competency of Drilling Contractors.

The drilling contractor must be a reputable operator with sufficient experience to accomplish the job. He must have as a part of his organization:

- a. An adequate drilling and coring rig.
- b. Competent rig operators.
- c. Adequate drilling and sampling tools.
- d. Sample containers other than bags and glass jars.
- e. Pressure testing equipment (if needed).

The contractor for negotiated engineering contracts must have in addition to the foregoing, competent technical personnel with experience in logging and classifying materials in accordance with systems used by the Service, and personnel who are qualified to prepare a geologic report in accordance with Service standards.

A prior inspection by Government Representative must always be made to determine if the equipment and other facilities are adequate to perform the job to be contracted.

## Site Investigation with Service-Owned and Operated Equipment

### Drill Crews.

When Service-owned equipment is used for site investigations, it is necessary to operate such equipment with Service personnel. The number and qualifications of members of the drilling crew varies in accordance with the type of equipment.

When a heavy-duty core drill is used and a power auger is normally employed as a companion piece of equipment, a drilling crew of 7 men is recommended to operate this equipment. The drilling crew should consist of one GS-9 geologist in charge, one GS-7 geologist to supervise operation of the power auger, one core-drill operator, one core-drill operator helper, one laborer IV, and two laborers II. When a combination rotary core drill and power auger drill is used a crew of 4 men is recommended, including a GS-9 geologist, a core-drill operator, one laborer IV and one laborer II. Smaller crews can be used, but will reduce the efficiency of the drilling operation. Maximum efficiency of core-drill work can be achieved only if the equipment is operated with a trained crew on a full-time basis. Part-time staffing of drillers is seldom satisfactory, but if it must be resorted to, the drilling crew should be employed elsewhere on the payroll on a permanent basis.

The GS-9 geologist serves as party chief and supervises the drilling crew. The GS-7 geologist on the drilling crew conducts the borrow investigations and other drilling done by the power auger, and assumes charge of the party in the absence of the GS-9 geologist.

Upon request, the advice and consultation of the engineering geologist of the Engineering and Watershed Planning Unit is available for on-site training and for consultation for complex investigations. This may include guidance on such matters as the amount, type, and depth of drilling required, degree and type of sampling, relief well exploration and installation, purchase of drilling accessories, and preparation of logs and geologic reports. Technical phases of the site investigations are correlated with design and construction requirements by the state conservation engineer to insure adequate information upon which to base designs, and permit proper control of construction operations.

## Preparation for Subsurface Investigations

### Assembling Maps, Reports, and Basic Data.

Available geologic information may modify the intensity of investigation. The data already obtained during the preliminary geologic examination (Chapter 8), in conjunction with the report from that examination, should be reviewed in detail. Need for additional information and data may be indicated from this study. The sources of information suggested in Chapter 8 may furnish more specific data on problems which might be encountered.

**Preliminary Plans and Profiles.**--Prior to initiating field work, the engineering survey information and such preliminary design data which are available should be plotted on Forms SCS-35A, 35B, and 35C so that the

geologist can locate and log the test holes and make necessary correlation between them. Figure 7-2 prepared on Form-35A shows the preliminary plan of the proposed structure including the centerline of the dam and the proposed centerline of the principal outlet structure and emergency spillway, the present stream channel, and a grid map of the proposed borrow area(s). Cross sections of the borrow area will be drawn on this sheet as the investigation proceeds.

Figure 7-3 prepared on Form SCS-35B shows the profiles of the proposed centerline of the dam and the principal spillway. When cross sections of the stream channel are needed they are plotted on this sheet as the investigation proceeds.

Figure 7-4 prepared on Form SCS-35C includes the proposed centerline of the emergency spillway and provides space for the cross sections of the emergency spillway which are developed during the course of the investigation. This form also provides space for additional profile and cross sections if any are needed, such as the profile in the downstream portion of the dam when borings are needed for toe drains or relief wells.

#### Acquiring Necessary Authorizations.

It is essential in all cases to obtain the landowner's permission to enter, cross, and exit from his land and/or property. Where property is to be removed (temporarily or permanently), displaced or rearranged, permission is also required. Permission must be obtained for the construction of roads, sumps, ditches, or ramps and the use and discharge of property owner's water, and for the construction of exploratory trenches, auger holes, test pits, cuts, stream displacement or obstruction. Necessary clearance is to be secured by the Work Unit Conservationist.

#### Preparation of Site.

When the activities of the survey crew and the drilling party are properly coordinated, the dam and reservoir areas should be cleared, staked, and mapped prior to the arrival of the drilling party.

The geologist should notify the project engineer at least one week before moving into the watershed.

**Staking and clearing.**--Locations of the centerline of the dam, centerline of the principal spillway, and cross sections of the emergency spillway should be staked. In many cases it is desirable to survey and stake an alternate location for the principal spillway. In areas of tall grass or weeds, lath and flagging should be used to locate the stakes.

All grid lines in the borrow area, the emergency spillway cross sections, and centerline of dam should be cleared, if necessary, to a sufficient width to provide easy access for the drilling equipment. It may be necessary to have one shallow water crossing over the stream in the borrow area. The centerline of the principal spillway should be cleared to a sufficient width for at least 150 feet upstream and downstream from the centerline of the dam.

## Plan and Distribution of Test Holes for Geologic Correlation and Interpretation

### Purpose and Objectives.

The purpose of detailed subsurface investigations of dam sites is to secure information needed for design, construction and operation. This includes identification, delineation, and correlation of underlying strata, determination of ground-water conditions, and the procurement of representative samples of materials for soil mechanics testing. The information required for specific sites is outlined under Detailed Subsurface Investigation in Chapter 3.

### General Procedure for Boring Dam Sites.

The boring of dam sites is primarily for two purposes: (1) to determine subsurface conditions of the site and (2) to obtain samples for soil mechanics testing. Experience has shown it to be more expedient to establish subsurface conditions of the site prior to obtaining samples. In this way, better representative samples can be obtained for the site as a whole, and duplication of samples is avoided. Less costly, small-diameter bore holes may be used for logging purposes while the drilling of larger-diameter holes may be restricted to only those holes where undisturbed samples need to be taken.

Bucket or slat augers and split-tube or thin-wall drive samplers are recommended for exploratory boring. Accurate logging of questionable thin-bedded and highly variable materials requires the use of split-tube drive samplers. Thin-wall drive samplers may be used for this purpose if the drilling rig is equipped with pistons for extruding samples (See figure 4-10).

The number, distribution and size of test holes and the number of samples required to establish subsurface conditions may vary widely from one investigation to another depending upon such factors as the variety and complexity of the conditions encountered. Sufficient test holes must be developed to enable the geologist to identify, delineate, and correlate the underlying strata, and to determine the kinds and locations of samples to be obtained. Where experience or previous examination indicates that shallow test holes are adequate, the use of hand tools or dozers and backhoes to excavate open pits may be adequate. Boring equipment should be used for exploration work exceeding 15 feet in depth.

### Numbering Test Holes.

The following standard system of numbering test holes is to be used:

<u>Location</u>	<u>Hole Numbers</u>
Centerline of dam	1-99
Borrow Area	101-199
Emergency Spillway	201-299
Centerline of Principal Spillway	301-399
Stream Channel	401-499
Relief Wells	501-599
Other	601-799

Principal spillway, channel and emergency spillway holes that fall on the centerline of the dam should be referenced to principal spillway, channel, or emergency spillway numbers rather than centerline of dam numbers. Holes placed in the foundation in the area of the base of the dam but not in the immediate vicinity of the centerline of the dam or appurtenances should be numbered as "other".

#### Determining Location of Proposed Test Holes.

It will be necessary to make exploratory borings along the centerline of the dam, along the centerline of the outlet structure, in the spillway area and in the borrow area or areas. Additional exploratory borings may be needed when relief wells or foundation drains are required or where it is necessary to obtain special information required by site conditions.

Foundation test holes.--Centerline investigations must determine whether there is stable support for the dam, whether all strata have sufficient strength to prevent crushing, excessive consolidation or plastic flow, and whether water movement through the foundation or abutments will cause piping, detrimental uplift pressure, or excessive water loss.

Conditions which must be recognized and located include the nature, extent and sequence of strata, presence of soluble salts, aquifers, and any weak bedding planes, joints, faults or other structural weaknesses in the underlying formation.

The spacing and number of test holes needed along the centerline of the dam, or beneath the proposed base, is largely dependent upon the complexity of the geology. Some of the more important elements include character and continuity of the beds, attitude of the strata and presence or absence of joints or faults. Depth, thickness, sequence, extent and continuity of the different materials must be determined.

A convenient system of boring for establishing site conditions is to locate initial test holes on the floodplain near each abutment, and one on the centerline of the outlet structure. Additional holes may then be interspersed between these and additional holes placed off the centerline to establish good correlation of strata. At least one hole should be put in

each abandoned stream channel that crosses the centerline. In addition, at least one hole will usually be required in each abutment unless a good surface exposure is available. The placing of a test hole at the intersection of the centerline of the dam and the emergency spillway serves a dual purpose.

Principal spillway test holes.--Complete information is required on the strata underlying the outlet structure. Such information is needed to determine the camber of the conduit and to ascertain if appreciable differential settlement will occur that might result in cracking of the outlet conduit. If the outlet conduit is to be located on or near rock with irregular surfaces, the profile of the rock surface must be accurately defined. The number of test holes required for this purpose will depend upon the configuration of the rock. If it is highly undulating, numerous test holes may be required so that the location of cradles and treatment of the foundation can be determined. In addition to the test hole at the intersection of the centerline of the dam and other holes to determine the configuration of rock, test holes will be required at the proposed riser location, at the downstream toe of the dam, and at the downstream end of the outlet conduit unless it is known that incompressible materials exist at these locations. For other types of outlets, boring requirements will vary widely from site to site, but sufficient borings must be made to permit design of structures that will be safe insofar as bearing and sliding are concerned.

Emergency spillway test holes.--It is necessary to determine the stability and erodibility of spillway material and to provide adequate information on the extent of the various types of material to be excavated and suitability of the excavated material for construction purposes. A series of geologic cross sections normal to the centerline of the spillway should be developed where highly variable conditions exist or long spillway sections are planned. Initially one section should be located approximately at the control section, one in the outlet section, and one in the inlet section of the spillway. Additional cross sections can then be located as needed for correlation, to locate contacts or obtain additional needed data. Test holes on each cross section should be located at the centerline and at the sides of the spillway. Where deep spillway cuts are planned, additional test holes may be required to determine the character of the material in the sides of the cut. When consolidated rock is present it is important to carefully delineate the rock surface and additional cross sections or holes may be required for this purpose, the number depending upon the rock surface configuration.

Borrow area test holes.--Investigations of the proposed borrow area are made to identify and classify the materials on the basis of their availability and suitability for use in constructing the dam. From these investigations the location and quantities of desirable materials and the areas in which the borrow pits may be most conveniently developed can be determined. These investigations must also determine the presence and extent of undesirable materials such as gypsum.

The borrow area should be gridded and the grid lines systematically identified such as by centerline station numbers and letters (See figure 7-2).

A convenient method of locating test holes is at the intersection of the grid lines starting with every second or third intersection and then interspersing test holes, if needed, for correlation or delineation.

Usually about 12 borrow area test holes will be sufficient for all but the larger structures, although local topography, geology and ground-water conditions may require considerable variation in the intensity of this study.

Reservoir basin test holes.--Local geologic conditions and the purpose of the structure may require subsurface exploratory work in the general site and reservoir area. The location, number and depth of such test holes will depend on the specific problem to be solved. If presence of cavernous or permeable strata in the reservoir area is suspected which might adversely influence the functioning or stability of the structure, it is necessary to put down test holes to determine those conditions in order to develop adequate safeguards.

Foundation drain and relief well test holes.--When exploration along the centerline of the proposed dam shows the presence of permeable materials, consideration should be given to the possible need for foundation drains and/or relief wells.

The determination of kind and location of drainage system to be used is the responsibility of the design engineer. The geologist should, however, recognize the problem and anticipate possible solutions in order to obtain sufficient information for design.

Relief wells are usually located at or near the downstream toe of a dam. Foundation drains may be located anywhere between the centerline and downstream toe depending upon specific problems and conditions. Either one or both foundation drainage methods may be necessary to control uplift pressure, facilitate consolidation or prevent piping. In many cases, deep foundation drains consisting of trenches backfilled with properly designed filter materials may be used as an economical alternate to relief wells. This method is adaptable in highly stratified materials and in those situations where confined aquifers can be tapped by feasible excavation.

Exploration should be carried downstream from the centerline to determine the extent and continuity of permeable substrata in all cases where the need for foundation drains is suspected. A series of accurately logged boring in the vicinity of the downstream toe, together with centerline information will usually provide sufficient data. Where foundation conditions are highly variable, additional test holes may be required between the centerline and downstream toe.

Stream channel test holes.--The stream channel may contain boulders, cobbles, gravel, sand, roots, debris, and organic matter which induce pervious conditions. It may be necessary to remove these materials as "special stream channel excavation" from beneath the dam. Normally this is required

from the upstream toe of the dam to a point two-thirds of the distance from the centerline to the downstream toe to prevent leakage through the foundation. Channel investigations provide information on the nature, quantity, and location of the deposits which are to be removed. Sufficient exploration should be made to determine this. These channels may be bored by the power auger unless the locations are inaccessible to such equipment in which case a hand auger or other hand exploration device may be used. A test hole should be placed, if possible, in the bottom of the channel. Test holes in stream channels should be so spaced that the volume of materials to be excavated can be estimated to within 25%.

Often the channel will be the best local source of sand or gravel for use in foundation drains, filter blankets and roadways. The geologist should carefully log these materials and indicate necessity for washing and screening if they appear to be suitable for these purposes.

#### Criteria for Determining Depths of Exploration.

Criteria for establishing minimum depths of exploration are presented in Chapter 3. In addition, the following criteria should be applied to foundation exploration.

Foundations.--Under usual conditions such as in alluvial valleys where the thickness of unconsolidated or compressible materials may exceed the proposed height of the dam, Service policy indicates "that investigations will proceed to a depth not less than the height of the dam unless unweathered rock is encountered" (See Engineering Memorandum SCS-33). Rock for this purpose should be interpreted as stable essentially incompressible materials which are not underlain, at least for a depth equal to the height of the dam, by unstable, compressible materials. Usually this includes such materials as shales and siltstones. Experience and knowledge of the general stratigraphy of the area may yield information on the thicknesses of these formations. Lack of positive knowledge of the formations requires the drilling of an exploration hole to the "minimum" depth specified as if it were unconsolidated material. There is usually no need for an undisturbed sample in such cases where there is no doubt as to the stability of the strata.

Where compressible material extends to a depth equal to the height of the dam, it may be necessary to extend the depth of exploration to a depth greater than the height of the dam. This depends upon the character of material encountered and the combined pressure exerted by over-burden and embankment. Tables 9-1 and 9-2 have been compiled to aid the engineering geologist in making this decision. Table 9-1 shows the approximate loading values of earth fill structures of various height of fill and at various depths. For example, a dam 50 feet high would exert a downward pressure of approximately 1.9 tons per square foot at a depth of 50 feet directly beneath the centerline of the dam. This, of course, can only be approximate because it varies with the density of the fill material, the shape and rigidity of the dam and the strength characteristics of the foundation material above the point of measurement. Figure 9-1 illustrates the assumptions upon which Table 9-1 is based.

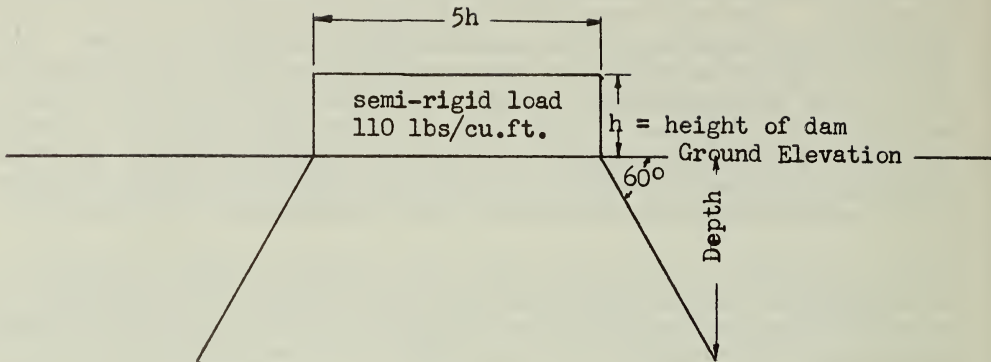


Figure 9-1 Vertical Stress on Foundations

Table 9-2 shows the presumptive bearing values of various unconfined materials under different soil conditions. These are the approximate loads to which these various types of soil materials can safely be subjected without excessive settlement. This is somewhat ambiguous because a given amount of settlement per unit thickness may be minor for a thin layer but would be excessive for a thick stratum.

Estimation of the soil condition must be made from examination of representative samples, drilling characteristics, or estimation of the dry density and void ratio of the material. Standard penetration tests,  $q.v.$ , or use of hand penetrometers may be helpful. The hardness scale on page 2-6 can also be helpful but, in general, is too rough an approximation, especially of the non-cohesive materials.

An example of the use of Tables 9-1 and 9-2 is as follows: The foundation for a dam 50 feet high has been drilled to the minimum depth of 50 feet. The bottom of the bore hole is still in compressible materials. The approximate vertical stress increment at this depth from a 50-foot dam would be 1.9 tons per square foot (Table 9-1). The material at the bottom of the hole has been determined to be an inorganic plastic clay (CH) which is fairly hard or stiff. Table 9-2 indicates stiff CH has a presumptive bearing value of 1.5 tons per square foot. This indicates that the formation is subject to deformation under the proposed load and that exploration must continue to greater depths until either more stable materials are encountered (preloading may increase the stability of CH materials as depth increases) or the vertical stress increment becomes less than the safe load value (in this case at a depth of 85 feet).

The maximum safe load value of the lowermost strata requiring an undisturbed sample or the uppermost strata not requiring an undisturbed sample must always be equal to, or preferably, exceed the vertical stress imposed by the dam.

Table 9-1

Approximate Vertical Stress Values of Earth Fill Structures Weighing 110 lbs. Per Cubic Foot  
(Tons/sq.ft.)

Height of Dam in ft.		Depth in Feet																									
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120	130	140	150	
5	0.2	0.1	0.1	0.1	0.1																						
10	0.5	0.4	0.3	0.3	0.2	0.2																					
15	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.3																		
20	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4															
25		1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6												
30			1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6								
35					1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8						
40					1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.8		
45					2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	0.9	
50						2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2	
55							2.4	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.6	1.6	1.6	1.5	1.5	1.4	1.3	1.3	
60								2.6	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.7	1.6	1.5	1.5	
65									2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.1	2.1	2.0	1.9	1.8	1.7	1.7	
70									3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.5	2.4	2.3	2.3	2.2	2.1	2.0	2.0	2.0	1.9	
75										3.2	3.1	3.1	3.0	2.9	2.9	2.8	2.7	2.7	2.6	2.6	2.5	2.4	2.3	2.2	2.2	2.1	
80											3.4	3.3	3.2	3.2	3.1	3.1	3.0	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.3	
85												3.6	3.5	3.4	3.4	3.3	3.2	3.2	3.1	3.1	3.0	2.8	2.7	2.6	2.6	2.6	
90												3.9	3.8	3.7	3.6	3.6	3.5	3.4	3.3	3.3	3.2	3.1	3.0	2.9	2.8	2.8	
95														4.0	4.0	3.9	3.8	3.8	3.7	3.6	3.6	3.4	3.3	3.2	3.1	3.0	
100															4.3	4.2	4.2	4.1	4.0	3.9	3.8	3.8	3.7	3.6	3.5	3.4	3.3

Table 9-2  
Presumptive Bearing Values - (Approximate Safe Load Values) of Soils  
Related to the Unified Soil Classification System  
(Tons/sq.ft.)

GW	GP	SW	SP	GM	GC	Hardness $\frac{1}{2}$			Soil $\frac{2}{2}$ / Condition	Hardness $\frac{1}{2}$	Cohesive							OH
						Non-Cohesive					SM	SC	ML	CL	OL	MH	CH	
6.00	5.75	4.50	3.25	3.50	6.25	4-5			Very Compact $\xleftarrow{\text{Hard}}$	2	2.50	3.25	2.50	3.25	2.00	3.25	2.25	1.50
5.25	5.00	3.75	2.25	2.80	3.50	3-4			Compact $\xleftarrow{\text{Stiff}}$	2	1.50	2.25	1.75	2.25	1.00	2.25	1.50	1.00
3.50	3.25	2.25	2.00	1.40	2.40	2-3			Firm $\xrightarrow{\text{Medium}}$	1	0.75	1.00	0.75	1.00	0.25	1.00	1.00	0.25
1.75	1.75	1.00	1.00	0.50	1.25	1			Loose $\xrightarrow{\text{Soft}}$	Less Than 1	0.50	0.50	0.25	0.50	--	0.25	0.25	--
--	--	0.50	0.50	0.25	0.25	1			Very Loose Very Soft	Less Than 1	0.25	0.25	--	0.25	--	--	--	--

$\frac{1}{2}$  See Hardness Scale, Page 2-6.

$\frac{2}{2}$  Dry density decreases from near maximum for very compact or hard soils to minimum for very loose or very soft soils. See Table 9-3.

It must be emphasized that these are approximate figures and are to be used only as criteria for increasing the minimum depth of exploration. The tables should never be used as justification for terminating explorations at depths less than the minimums set forth in Chapter 3 unless unweathered rock is encountered.

### Plan and Distribution of Test Holes for Obtaining Samples

#### Purpose and Objectives.

Samples are used for laboratory tests to determine the physical properties and behavior of materials when subjected to specific conditions. The results of such tests are then used to predict changes which might occur in materials at the site as a result of construction and operation of a dam. Such test data provide a basis for developing certain aspects of the design to provide a safe, economical and practical structure.

The important considerations in sampling are that the samples taken be truly representative and that they be adequate in dimension and character to facilitate the desired tests. The kinds of samples to be taken at a particular site depend upon the nature of material encountered, size of structure, purpose, etc. The number of samples depends upon variability of materials encountered. Minimum requirements for sampling are outlined in Chapter 3 by group classification.

#### General Procedures for Sampling.

Whereas disturbed samples may be obtained at any time during the course of a geologic investigation, the taking of undisturbed samples should not be attempted until the stratigraphy of the site has been delineated.

Upon completion of exploratory borings, the geologist should study the geologic profiles and review his field logs to determine the distribution of various distinctly different strata. Depending upon the nature, extent, location and depth of an individual stratum, the type of sample needed (disturbed or undisturbed), and the most appropriate location and depth for obtaining the sample must be determined. Where alternate locations for sampling a particular stratum exist, consideration should be given to the possibility of obtaining the sample where other strata can be sampled from the same hole. This will reduce to a minimum the number of sampling holes required.

The stratigraphy of the site, logs of borings and proposed sampling procedures should be discussed in detail with the project engineer prior to proceeding with undisturbed soil sampling. Specific geologic conditions which may require alteration of preliminary design should be pointed out to the engineer. Thus, if there is a need for relocation of the emergency spillway, the principal spillway, borrow area, the centerline of the dam, or other change in preliminary design because of subsurface conditions, the geologist can proceed with alternate or additional exploration boring or sampling as needed.

Since the taking of an undisturbed sample for shipment to the laboratory does not permit convenient visual inspection of the sample for logging

purposes, it is expedient to place a sampling hole close to a previously logged exploratory boring. The stratigraphic sequence normally is similar in the two holes and the depth and type of sample to be obtained can be predetermined.

Previous experience in geologic site investigations demonstrates that the foregoing procedure provides the most satisfactory method of obtaining representative samples. It also provides the most economical means of investigation because it relates the number of the more costly, larger-diameter holes to be bored to sampling requirements and eliminates unnecessary duplication.

#### Numbering Sample Holes.

Usually small (4 lb.) disturbed samples can be obtained from the test holes bored for logging and correlation purposes. When undisturbed samples or large disturbed samples are required, however, it will be necessary to bore special holes of adequate diameter for this purpose.

Special sample holes should be numbered according to their location. Usually such a hole is immediately beside a logged hole. In this case, the sample hole is not logged and is given the same number as the logged hole. Such a sample hole would not be plotted on the plans and profiles as a separate hole, but the symbol on the plan would be changed from a dot to a circled dot (See figure 7-2) and the sampled zone would be delineated on the graphic log.

#### Obtaining Disturbed Samples.

Disturbed samples are to be taken in accordance with minimum requirements for group sites as set forth in Chapter 3 and as described in Chapter 6. They are needed for routine laboratory analyses to determine gradation, Atterberg limits, dispersion, compaction, solubility, shear strength of remolded samples, etc. The need for a disturbed sample and the size of the sample depends upon the nature of material and its location.

Small (4 lb.) samples should be taken for routine laboratory identification of all distinctive strata found at the site. These samples may be obtained during the exploratory stage of the investigation. A general rule is to obtain such a sample for each distinct change in strata in the bore hole, or, at minimum 5-foot intervals. Where a large number of exploratory holes are required to determine complex stratigraphy, an unnecessarily large number of samples will result if this general rule is followed. In this case, duplicate samples should be eliminated after the stratigraphy has been determined. Materials which are difficult to classify on the basis of field tests and boundary classifications may require more than one sample per strata, particularly if there is reason to believe that variation occurs within the strata or dispersed solids or soluble salts are suspected. Samples should not be taken of materials brought to the surface by either wash boring or continuous flight augers. Because of mixing and sorting action, such samples are not considered to be representative samples. The best method of obtaining small disturbed samples of fine-grained materials is by means of a split-tube sampler, thin-wall drive sampler or bucket auger.

When the volume of material required for the larger (25 lb.) samples needed for compaction and other tests cannot be obtained from the exploratory borings separate sample holes are required. Samples should be obtained from the major distinctive strata in the borrow areas and excavated emergency spillway areas where the materials may be suitable for use as core or fill. Minor lenses of material which would have little influence on the total fill material, or which might be readily disposed of in construction operations should not be sampled other than possibly a small hand sample for identification purposes. Furthermore, there is no advantage to be gained in obtaining 25-pound samples below the water table unless the geologist has reasonable assurance that an abnormally high water table exists at the time of the investigation or the borrow area can be successfully drained.

#### Obtaining Undisturbed Samples.

Undisturbed samples are needed to predict stability characteristics of in-place strata in the foundation of the dam. These characteristics may vary during and after being subjected to loading. Need for undisturbed samples, therefore, is normally limited to the area under the embankment and the principal spillway. The tests conducted on such samples are shearing strength, consolidation, and permeability. Major problems of permeability are associated with coarse-grained soils while those of shear and consolidation are associated with fine-grained soils.

By the time the geologist has completed his exploratory boring and determined the stratigraphy, he will have an understanding of the nature of the materials and their distribution. The presence of appreciable clay minerals in the soil profile calls immediate attention to possible problems of shear and consolidation. Clay minerals vary widely as do their engineering properties. If such minerals occur within a depth equal to the height of the dam, problems of shearing strength arise. The closer such materials are to the surface the more acute the problem. Shear is of greatest concern in the strata immediately below the dam to a depth equal to about one-third the maximum height of the dam. Problems of consolidation may extend to depths much greater than the height of the dam and become more acute the higher the dam.

The problems of shearing and consolidation are related to the nature of mineral constituents, void ratio, and other factors. Measurements of these factors are restricted to the laboratory so that other means of recognition of problems of consolidation and shear must be resorted to in the field.

The classification of clays according to previous loading conditions basically separates clays into two main groups: (1) normally loaded clays, and (2) preloaded (or precompressed) clays. It is difficult to distinguish between the two groups by unit weight alone. The inference of the geologic history of the site from a study of the topography and geologic features of the site may often be more indicative of which of the two conditions applies. It must also be recognized that clays can be precompressed by desiccation as well as by consolidation under loading.

Precompressed clays are not incompressible although they are less compressible than normally loaded clays. The compressibility of precompressed clays varies with the ratio of the pressure added by the structure to the difference between the precompression load and the present overburden pressure ( $\Delta P/P_0 - P_0$  see Section 9, National Engineering Handbook). Although most precompressed clays are stiff clays, if the precompression load was less than 4 tons per square foot they may be encountered in the soft condition.

Estimating in-place dry density versus maximum density may provide a rough estimate of state of consolidation of materials encountered. Table 9-3 lists the range in minimum and maximum dry densities of some typical materials as a guide to estimating in-place and maximum density relationships. The unconfined compressive strength of some materials can be estimated in the field on the basis of standard penetration tests.

#### Determining Sampling Needs.

Foundation samples.--Undisturbed samples for shipment to the soil mechanics laboratory should be taken of all questionable soils at the intersection of the centerline of dam with the centerline of the principal spillway. Undisturbed samples also will be taken at other points along the centerline of the dam if materials of questionable bearing strength or permeability are encountered which cannot be correlated with strata at the intersection of the centerline of the dam and principal spillway. Additional undisturbed samples should always be considered if the proposed dam is more than 35 feet high.

Disturbed 25-pound samples from each distinct horizon in a proposed cutoff trench area should be obtained for compaction analysis if the material which might be excavated is suitable for use in the embankment. Four-pound disturbed samples should be taken for classification of all other soil horizons and of the same horizons from different holes if needed to verify correlation.

Cores should be taken of compaction-type shales for slaking (wetting-drying) and freezing-thawing tests. Foundations of these materials may require special treatment such as spraying with asphalt or immediate backfilling of the cutoff trench upon exposure. Rebound following unloading may also be a problem in some types of shale. The geologist should specify what laboratory tests he believes will be required, for both soil and rock samples.

Principal spillway samples.--In addition to the hole at the intersection of the centerlines of the dam and principal spillway, additional holes should be drilled as necessary. In unconsolidated materials, a minimum of holes would include one at the riser site and one at the downstream toe of the dam. Where these materials are of questionable bearing capacity or differ from those in the hole at the intersection with the centerline of the dam undisturbed samples should be obtained.

Emergency spillway samples.--Large disturbed samples should be taken. Samples from the same horizon in various holes may be composited if correlation is assured. At least one such sample of each material should be taken. Samples of materials from the emergency spillway area should not be composited with those from the borrow area.

Table 9-3

Dry Density Ranges of Various Soils <sup>1/</sup>

Soil Description	Dry Weight (lbs./cu.foot)	
	Min. (loose)	Max. (dense)
Non-Cohesive (granular) Materials		
1. Uniform Materials		
a. Clean, uniform sand	83	118
b. Uniform inorganic silt	80	118
2. Well-graded Materials		
a. Silty sand	87	127
b. Clean fine to coarse sand	85	138
c. Micaceous sand	76	120
d. Silty sand and gravel	89	146 <sup>2/</sup>
Mixed Soils		
1. Sandy or silty clay	60	135
2. Poorly-graded silty clay with gravel	84	140
3. Well-graded sand, silt and clay mixture	100	148 <sup>2/</sup>
Cohesive Materials		
Clay Soils		
1. Clay (30 - 50% clay sizes)	50	112
2. Colloidal clay (50% less than 2 microns)	13	106
Organic Soils		
1. Organic silt	40	110
2. Organic clay (30 - 50% clay sizes)	30	100

<sup>1/</sup> After Hough, B. K., 1957<sup>2/</sup> Applicable to very compact glacial till.<sup>3/</sup> Applicable to hardpan.

When rock excavation is involved, undisturbed cores of rock materials should be taken. Rock cores usually are left at the site, but representative samples of shale cores must be dipped in paraffin to protect them from weathering. Although soft shales may be classified as common excavation, it is desirable to obtain cores for later inspection by prospective contractors. Cores of soft rock should be sent to the laboratory for testing to determine their best use.

Borrow area samples.--The purpose of sampling borrow materials is to obtain representative samples in order to evaluate suitability of the various materials for construction purposes. Large disturbed samples are obtained of each type of unconsolidated materials for Atterberg limits, mechanical analysis, moisture-density, compacted shear, and compacted permeability tests as required. The number of samples required per site will depend upon the variability of the borrow materials. For an average site 6 to 8 large samples should be adequate, although some sites will require more and some less. Undisturbed samples need not be taken of borrow material.

In addition to the physical characteristics of soil materials, field moisture and ground-water conditions should be determined. In many areas of intermittent streamflow, even the alluvial soils have a moisture content far below optimum required for compaction to obtain maximum densities.

On the other hand some alluvial floodplains have an inherently high water table. Alluvial soil materials in such areas are not generally good sources of borrow since heavy earth-moving equipment will mire in the wet areas, and the saturated soil requires drying to optimum moisture content.

Samples for field moisture determinations should be taken of all unsaturated fine-grained materials where standard penetration tests are made. Samples taken with a split-tube sampler are adequate for this purpose. The length of these samples must be carefully measured to establish the volume and the sample must be immediately sealed in a wide-mouth jar to avoid moisture loss. Length and diameter of sample must be recorded on the label along with other pertinent information discussed elsewhere. Other methods of determining sample volume and field measurements of in-place density are discussed in Soil Tests for Military Construction (see reference list under Soil Mechanics).

In borrow areas where water table conditions are permanently high, the collection of borrow samples of cohesive materials below the water table serves no useful purpose.

Samples from the same horizon in several holes may be composited if good correlation has been established. The Soil Sample List (figure 9-3) must show from where the material in a composite sample was taken (which holes, and what depths in each hole).

When 25-pound, composite, borrow samples are taken it usually is unnecessary to take small disturbed samples in addition. However, if dispersion is suspected, small separate samples should be taken from each hole. The geologist should advise the laboratory, in his geologic report, and on Form SCS-534, what tests other than compaction may be required.

The location of all holes drilled and sampled should be shown on both the plan and cross sections of the borrow area on the geologic investigation sheets (see figure 7-2).

At most flood-water retarding dam sites sources of borrow and core material will have been noted by the geologist during the preliminary geologic examination. If more information is needed by the engineer, he may consult a geologist before he completes a layout of the grid system for borrow area. For some borrow areas it may be desirable to make one or two hand auger borings before completing this layout.

Reservoir basin samples.--Large (25-pound) soil samples, representative of the bottoms and sides of farm ponds and storage reservoirs should be submitted for sites where moderate or excessive leakage is suspected. Where bottom conditions vary, separate samples should be obtained for each type of condition. In the event local soils are to be used for blanketing or sealing, 25-pound samples of each type of soil proposed to be used for this purpose should also be submitted. Samples for determining permeability of reservoirs or pond bottoms should be collected from the surface 12 inches of the present or proposed pond bottom and from the sides of the reservoir. Where borrow is to be removed from the pond area, samples must be secured from below the proposed borrow depth for permeability tests. Reservoir or pond bottoms are not the only source of seepage problems. More water may be lost through the sides than through the bottom.

Relief well and foundation drain samples.--If an exploration hole reveals a permeable stratum which might require drainage, a second hole should be drilled and undisturbed samples taken, if possible, for permeability determinations. Continuous undisturbed samples need to be taken from the surface of the ground to two feet below the bottom of the permeable stratum. However, it is almost impossible to obtain truly undisturbed samples of permeable materials. A disturbed sample incorrectly labeled as an undisturbed sample may give grossly erroneous results in the laboratory determinations of permeability. It is usually better to determine the permeability or transmissibility (permeability times thickness) of an aquifer or aquifers in the field by means of pump tests. Pump-in tests should be used if the entire aquifer or potential aquifer is not saturated. Methods of conducting pump tests are discussed in Chapter 4.

If pump test methods are used, representative, but not necessarily undisturbed, samples must be secured for use in the design of the well and filter.

The geologist should log in detail information on the depth, thickness, and types of material encountered in each aquifer. The laboratory will furnish information on the length of screen, slot size, and filter material to be used after testing the representative samples.

All relief wells recommended by the geologist for consideration must be completely drilled and sampled. The locations of all holes are to be plotted on the plan of the geologic investigation sheets.

In some areas corrosion or incrustation of the well screen may be a problem. In such cases the geologist should obtain a sample (1 quart) of the ground water at the site. This is sent to the laboratory for such tests as parts per million of alkalinity, chlorides, iron, and total hardness; and pH value. On the basis of these tests the laboratory may recommend a different metal for the well screen than the red brass ordinarily used, such as stainless steel, or silicon red brass.

It is very important that the geologic investigation for relief wells be made in sufficient detail to include all areas possible for its final position. If it is necessary to move it to another location later, it may be found that no aquifer exists at the new location. If the location of a proposed relief well is changed by more than 5 feet from the sampled site, additional exploratory borings need to be made.

If the type and size of material in the aquifer differs at the new location, it will be necessary to take new samples and obtain the laboratory's recommendations. A change may be required in the recommended filter pack gradation, length of screen, or slot size from that proposed at the original location.

If investigations of the centerline of the dam reveal the presence of aquifers or porous strata at shallow depths (20 feet or less) foundation drains may be required. Very pervious or sandy borrow material also may necessitate foundation drains.

The purpose of foundation drains is to reduce uplift pressures and forestall the possibility of sliding or slumping of the downstream section.

Sufficient borings should be taken along the proposed drain lines to determine the depth and thickness of any aquifers, and also to locate sources of filter pack material if possible. Disturbed 4-pound samples for mechanical analysis should be taken of each horizon in which the drain may be placed. These samples usually will be of pervious material but in some cases, where it is necessary to pass the drain through impervious horizons because of grade requirements, samples of this material also should be collected.

The geologist should provide information on the depth, thickness, and type of pervious materials encountered. The laboratory will provide more detailed information as to the type of drains, outfall elevation, grade, and filter pack required.

Stream channel samples.—The geologist should note whether or not the stream channel gravels and sand are suitable for filter materials in toe or bank drains, for relief well gravel packing, or for road materials. Material must be well-graded, less than 3 inches in size and contain not more than 5% of materials that will pass the 200 mesh sieve. If the material is suitable and can be used it should be stockpiled; otherwise recommendations should be made by the geologist for a location for wasting this material. If gravels and sands appear to be suitable for foundation drains, samples should be taken for the soil mechanics laboratory to make mechanical analyses, so that recommendations can be made for their use in the dam.

Soil stabilization measures.--Samples required for soil stabilization measures should be representative of the area where the measures are to be installed. The number of samples taken depends upon the areal extent of the treatment and upon the type or types of soils encountered. Generally, in a homogeneous soil, a single sample should be sufficient. However, variation in soil types may require two or three representative samples. Tests for soil-cement or other chemical soil stabilization measures require very large (75 pound) samples.

#### Identification and Shipment of Samples

The tins, cans, metal liners, or other protective containers for undisturbed samples should have the following identifying features: (1) Location of project, (2) project or site name and number, and fund classification, (3) location of sample on the site, (4) test hole number, and (5) sample depth. The top and bottom of the samples must also be indicated.

These identifying features should be applied with a brush, pen, paint, stencil or other permanent marking device. Marks from ordinary pencil, pen or wax crayon are easily rubbed off.

Bag samples of disturbed material should be tagged with cloth (linen) shipping tags (see figure 9-2) which show the following: (1) Location of project (State and town or community), (2) site or project name and number, (3) fund classification of project (FP-2, WP-1, WP-2, CO-1), (4) location of sample on the site (centerline station, borrow grid, etc.), (5) test hole number, (6) field number of sample, (7) depth of sample, and (8) date and collector.

Since tags are often pulled off of bags in transit, a duplicate tag with the above information should also be placed inside the bag.

In order to expedite the sorting, numbering and handling of samples in the laboratory, field numbers of samples should conform to test hole numbers with suffixed decimals to indicate number of samples from the same hole. For example, sample numbers 1.1, 1.2, 1.3 would indicate 3 samples from test hole No. 1; numbers 101.1, 101.2 would indicate 2 samples from hole No. 101.

Standard forms covering the description of samples and the test-hole logs and copies of plans and profiles should be transmitted to the laboratory under separate cover at the same time that samples are shipped. A copy of the geologic report should be sent to the laboratory as soon as possible after completion. Material to be transmitted to the laboratory is summarized as follows:

- a. Standard Form SCS-533, "Log of Test Holes" (see figure 7-5).
- b. Standard Form SCS-534, "Soil Sample List - Soil and Foundation Investigations" (see figure 9-3). This sample list should show individual holes, or samples, involved in composited

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SCS-172

U. S. Department of Agriculture  
Soil Conservation Service

SOIL CONSERVATION SERVICE  
SOIL MECHANICS LABORATORY  
800 "J" Street  
LINCOLN, 8, NEBRASKA

Front

O

Location \_\_\_\_\_

Watershed \_\_\_\_\_

Sub W.S. \_\_\_\_\_

Site No. \_\_\_\_\_  
or Name \_\_\_\_\_

Project ( ) FP-2, ( ) WP-1,  
( ) WP-2-1, ( ) WP-2-2,  
( ) CO-1

Test Hole  
Location \_\_\_\_\_

Sample

Hole No. \_\_\_\_\_ No. \_\_\_\_\_

Sample Depth \_\_\_\_\_

Collector \_\_\_\_\_

Date \_\_\_\_\_

Back

Figure 9-2 Shipping Tag for Soil Samples

samples when such mixtures are prepared in the field. The sample list should give information on method of transportation and Government bills of lading.

- c. Standard Forms 35A, 35B, and 35C, "Plan and Profiles for Geologic Investigations" (see figures 7-2, 7-3 and 7-4).
- d. Copy of geologic report (see figure 9-5).

- e. Copy of report on interpretations, conclusions and suggestions (see figure 9-6).

At the time that samples are sent to the soil mechanics laboratory, copies of the various forms, geologic report, and interpretations, conclusions and suggestions should be sent to the State Office. This information is needed to prepare Standard Form SCS-356, "Request for Soil Mechanics Laboratory Test". Form SCS-356 is an administrative form used for commitment of funds to reimburse the laboratory for cost of sample analyses. An alternate procedure would be to supply the State Office with a copy of Form SCS-356, containing such information which the geologist might supply. Figure 9-4 illustrates the kind of information which might be supplied by the field geologist on this form.

Large bag samples are generally shipped by freight or express using the proper address on each tag. Large numbers of small bag samples can be packaged together and also shipped by freight or express.

Small bag samples not exceeding 4 pounds per sample can be sent via "franked mail".

Large numbers of undisturbed core samples can be shipped "as is" if enclosed in rigid containers (Denison tins, etc.). Each tin should, however, show the proper address. Small numbers of undisturbed samples should be boxed or crated for shipment.

A Government bill of lading must be obtained from the State Office when samples are shipped by freight or express.

### Investigation of Ground Water

#### Purpose and Objectives.

Water investigations are to be conducted for the purpose of determining depth to water table. A relatively shallow water table requires the taking of data for use in establishing control of the water during the construction and after completion of the structure. A deep water table requires the collection of information relative to the behavior of strata above the water table when ponded water is to be superimposed on them by the action of the structure. In addition, water found in or near the site may be needed for use in construction, or for water supplies.

The behavior of water under varying conditions and for varying reasons must be determined. Therefore, the gradient, rates of flow, direction of flow, quantity and quality must be known as required.

#### Procedure.

In developing plans for a dam, it must be recognized that the impoundment of water by a dam results in the greatest disturbance of ground-water and surface-water relationships caused by any type of engineering structure. Therefore, the geologist must give special attention to rock formation, geologic structure and alluvial zones in which alterations in water movement will be produced by a dam.

SHEET \_\_\_\_\_ OF \_\_\_\_\_ SHEETS

DISTRIBUTION:  
ORIG. & 3 COPIES TO S.O.  
STATE OFFICE APPROVES &  
SENDS 2 COPIES TO S.M.L.

# REQUEST FOR SOIL MECHANICS LABORATORY TEST

FOR USE OF ORIGINATING OFFICE	FOR USE OF ORIGINATING STATE OFFICE	FOR USE OF SOIL MECHANICS LAB.
FROM <u>Joseph Doaks</u>	ORDER NO. _____	LABORATORY WORK ORDER NO. _____
ADDRESS _____	APPROPRIATION _____	DATE SAMPLES RECEIVED _____
DATE <u>9/23/58</u>	AMOUNT ENCUMBERED \$ _____	
REPORT TO _____	TECHNICAL APPROVAL _____	
	ADMINISTRATIVE APPROVAL _____	

TO BE FILLED IN BY ORIGINATING OFFICE

1. NUMBER OF SAMPLES: UNDISTURBED 2 - Denison, 5 1/8" 6 - 25 lb. borrow  
3 - Shelby, 3" 12 - 4 lb. classification

2. SITE OR PROJECT Olive Branch No. 17

3. WATERSHED OR LOCATION Greentree, 5 miles SE of Watertown, any State

4. PROGRAM CLASSIFICATION: CO-1 ( ), WP-1 ( ☒ ), WP-2-1 ( ), 5. ESTIMATED TESTING COST \$ 815.  
 WP-2-2 ( ), FP-1 ( ), FP-2 ( ), FP-3 ( ), GP ( ), SB ( )

6. DESCRIPTION OF PROJECT (PLANS, PROFILES AND GEOLOGIC REPORTS SHOULD BE SUBMITTED IF AND WHEN AVAILABLE):

A. EARTH DAM CONSTRUCTION: DAMAGE CLASS (Eng. Memo. 27) b MAXIMUM HEIGHT OF DAM 35'

ELEVATIONS: TOP OF DAM \_\_\_\_\_ PERMANENT POOL \_\_\_\_\_ EMERGENCY SPILLWAY \_\_\_\_\_

INVERT OF PRINCIPAL SPILLWAY OUTLET \_\_\_\_\_ UPSTREAM BERM \_\_\_\_\_ DOWNSTREAM BERM \_\_\_\_\_

WIDTH: UPSTREAM BERM \_\_\_\_\_ DOWNSTREAM BERM \_\_\_\_\_ FLOODWATER DETENTION TIME \_\_\_\_\_

PROPOSED SLOPES: UPSTREAM \_\_\_\_\_ DOWNSTREAM \_\_\_\_\_ CLASS OF FILL \_\_\_\_\_

(Standard Specifications SCS)

EQUIPMENT TO BE USED \_\_\_\_\_

FOUNDATION CONDITIONS IF NOT SAMPLED: \_\_\_\_\_

OTHER IMPORTANT FACTORS OR PROBLEMS: Forms SCS-533, 534, 35A, 35B, and 35C  
transmitted to SML, 9/23/58

B. RESERVOIR SEALING:

MAXIMUM WATER DEPTH \_\_\_\_\_ POND BOTTOM AREA \_\_\_\_\_

ESTIMATED SEEPAGE LOSSES \_\_\_\_\_ PREVIOUS TREATMENT \_\_\_\_\_

OTHER PERTINENT FACTORS (DEPTH TO GRAVEL, LIMESTONE SINKS, ETC.) \_\_\_\_\_

C. OTHER PROJECTS (SPECIFY - SOIL CEMENT STABILIZATION, CANAL BANK STABILITY, LAND SLIDES OR OTHER)

7. REMARKS ON ANALYSES DESIRED: Mechanical analysis - 25; Shear, 4 foundation, 2 borrow  
at optimum and saturated moisture; Compaction - 6; Consolidation - 3;  
Atterberg, 7 foundation, 6 borrow; dry unit weight, 7; Specific gravity - 7.

All zones of seepage at and near a dam site should be investigated. These may range from slow movement of water from a slightly permeable horizon to active flow from an aquifer under artesian conditions. If the seepage occurs at the end of the earth-fill, it can cause dangerous saturation of the fill. Some occurrences of this type may be corrected by drainage or diversion of the water from the immediate vicinity of the dam. Diversions must be developed in such a manner, however, that the slope above the dam is not sufficiently disturbed to cause slides. Seepage from limestone formations must be controlled. For example, a channelled limestone may be responsible for a slow seepage which is mostly concealed by several feet of overburden. If an excavation is made in the vicinity, the removal of overlying material may reveal an active spring. Cracked and fissured igneous formations may have seepage from joints.

Where a dam is built in a deep valley, one or more zones of seepage may occur on the slopes well above the elevation of the dam. In most such cases it is possible to divert the water from such sites upstream or downstream where it will not endanger the fill.

Construction problems caused by springs are similar in most ways to those resulting from seepage, except that the flow is more active and quantities of water are greater.

Large springs flowing from valley slopes above a dam site are conspicuous and easily identified. Smaller springs, especially if they are intermittent, are more difficult to identify and estimation of their flow is uncertain. Many aquifers which crop out along the valley slopes have confining beds beneath them which may be responsible for an unstable condition along the slope. In some cases springs flowing from fractured zones in consolidated rocks can be blocked or diverted from a dam site by grouting. The same treatment can be applied to vesicular lava formations.

The springs which issue from the base of a permeable formation on the upland can be diverted more readily from a dam site, but they are also more apt to be intermittent and escape notice upon first examination. Features of this type are more easily studied soon after substantial rains have occurred.

Most springs occurring in valley bottoms are manifestations of the water table, and they may contribute water flow to a depression such as an excavation, an abandoned meander or to an active channel. They are a part of the ground-water system in the valley, and can be treated as a part of it when the fill, core, outlets and drains of a dam are constructed. An artesian spring from an aquifer which is penetrated by a valley is a notable exception. In all cases where studies of springs are involved at a dam site, two fundamental considerations must be recognized; (1) A spring may cause great difficulty and expense in construction if it occurs at or close to a dam site, and (2) a spring in a reservoir basin, and not affecting a dam, can be a substantial asset if impoundment of water is important.

Even a brief list of springs and their problems at and near a dam site indicates their variety and complexity. Therefore, all field geologists

should assemble the most complete and detailed information possible on springs to permit the engineers to prepare proper designs for safe and and stable dams.

Ground water affecting design and construction of dams.--Virtually all possible ground-water situations can be encountered when investigating dam sites. The chief consideration, however, is its probable effect on design and construction. The ground water encountered in the dam site investigations is primarily in valley slope and valley bottom areas. In most cases the water in the valley alluvium requires the most thorough investigation and planning for design and construction of a dam. Since most earthfill dams are not actually watertight, a slow seepage through the dam can be tolerated if erosion and the development of piping are prevented. These factors are subject to detailed study by the soil mechanics laboratory when it prepares its recommendations for construction of the fill.

The investigation of ground water at a dam site should include a study of contributions of ground water to the stream as well as assembly of data on the water table elevations in the valley and the water in deeper zones separated by less permeable beds. Much of this information will be obtainable from a study of ground-water conditions in the test holes.

Measurements of water levels in test holes should be made one or more days following drilling to allow time for stabilization of water level. This information, together with known seasonal fluctuation, will indicate the amount of wet excavation which will be encountered in developing the borrow pit and constructing the core, cutoff walls, and other features.

#### Determining Need for Water Samples.

When local sources of water are available in sufficient quantity for construction needs, yet there is doubt about its quality, samples of the water should be taken for chemical analyses. For example, highly saline or alkaline water should not be recommended for use in construction.

#### Determining Need for Aquifer Samples.

Samples of materials forming an aquifer are needed when water supply or recharge is being contemplated. Likewise, samples are needed when there is indication that grouting or cutoff curtains will be required to stabilize structural foundations overlying water-bearing materials. Sampling of an aquifer is required where need for relief wells is anticipated in order to provide information for the design of gravel packs and screens.

#### Determining Need for Field Tests.

In water investigations the following conditions may merit field tests as follows:

- a. Need to determine quantity of ground water readily available for construction: by pump-out tests.

- b. Steady or sudden loss of drilling fluid in test holes. The horizon may be located by pressure tests and where pressure loss exceeds 10 p.s.i. per minute, the loss may be measured by pumping tests.
- c. Material whose characteristics and position indicate a possibility of leakage. A pressure test on this zone may be a worthwhile precautionary measure.
- d. Where seepage, as through the foundation, is suspected, dye indicators may be used to trace the waterflow.
- e. Piezometers may be installed to measure hydraulic pressures and gradient for estimates of ground-water flow.
- f. Where artesian conditions exist a flow meter test will measure the quantity of flow.
- g. Where ground-water recharge is to be effected, tests may be desirable to determine if recharge wells into an aquifer are merited.

#### Other Field Tests

##### Purpose and Objectives.

Where tests can be made in the field to obtain needed information it will be preferable to do so for it may reduce the number of samples shipped to the soil mechanics laboratory. Determinations at the site of investigation are normally more economical and time saving thus expediting the completion of the investigation.

Tests that may be made in the field include determining penetration resistance, field moisture, field density and vane shear.

##### Penetration Tests.

Where data on naturally compacted soil is desired in lieu of, or in conjunction with undisturbed samples, a penetration test may be obtained. Determination of penetration resistance corresponds to a sounding test and provides advance information on density, consistency and bearing capacity.

Following is the Standard (Terzaghi and Peck) penetration resistance table. Results are most directly applicable to non-cohesive soils.

Table 9-4

## Standard Penetration Resistance

Non-Cohesive Soils		Cohesive Soils	
Blows per Foot	Relative Density	Blows per Foot	Consistency
Less than 4	Very loose	Less than 2	Very soft
4-10	Loose	2-4	Soft
10-30	Medium	4-8	Medium
30-50	Dense	8-15	Stiff
Over 50	Very dense	15-30	Very stiff
		Over 30	Hard

Vane Shear Tests.

Vane shear tests may be made in soft cohesive material where undisturbed samples of foundation materials are not taken. The data obtained can serve as a useful supplement to information obtained from undisturbed samples submitted to the laboratory. However, vane-shear testing equipment is relatively new and the equipment and interpretations subject to further refinement. For this reason, it is not recommended for general Service work.

Report of Detailed Geologic InvestigationNarrative Report.

The report of geologic conditions of a structural site will be as brief and concise as possible and still cover all geologic problems thoroughly. This report may be prepared in narrative form, or may be developed in outline form on standard reporting forms (see figures 9-5 and 9-6). Simple easily understood terms should be substituted for highly technical geologic terms wherever possible. For example, use "sandy" rather than "arenaceous" and "clayey" rather than "argillaceous". When it is necessary to use uncommon geologic terms, explain the exact meaning immediately following the first point of usage. For example, "vugular limestone (limestone containing small cavities)".

The narrative report will clearly set forth the methods of investigation and the facts revealed. Included with the report will be copies of all field logs and copies of completed plan and profile sheets for geologic investigation (see figures 7-2, 7-3, and 7-4).

There will also be prepared a supplement to the report to be designated "For In-Service Use Only".

The following outline may be used in preparing the narrative report:

I. Introduction

A. General

1. Date of exploration
2. Personnel engaged in exploration
3. Watershed (name and location)
4. Site number
5. Site group and hazard class
6. Location
7. Equipment used (type, size, makes, models, etc.)
8. Site data
  - a. Size of drainage area above (square miles and acres)
  - b. Maximum pool depths
    - (1) Sediment pool
    - (2) Flood pool
  - c. Dam
    - (1) Height
    - (2) Length
    - (3) Location of spillway
    - (4) Volume of fill

B. Surface Geology and Physiography

1. Physiographic Area
2. Topography
  - a. Steepness of valley slopes
  - b. Width of floodplain

3. Geologic formations and surficial deposits
  - a. Names and ages (Jordan member, Trempeleau formation, Cambrian Age; Illinoian till; Recent alluvium)
  - b. Description
  - c. Topographic position
4. Structure
  - a. Regional and local dip and strike
  - b. Faults, joints, unconformities, etc.
5. Evidence of landslides, seepage, springs, etc.
6. Sediment and erosion
  - a. Gross erosion, present and future, by source
  - b. Delivery rates
  - c. Sediment yield
  - d. Storage requirements and distribution
7. Downstream channel stability
  - a. Present channel conditions
  - b. Anticipated effect of the proposed structure

## II. Subsurface Geology

### A. Centerline of the Dam

1. Location and types of test holes, and numbers of samples of each type collected.
2. Depth, thickness and description of pervious or low volume-weight strata encountered. Give detailed data on aquifers and/or water-bearing zones.
3. Depth and description of firm foundation materials.
4. Location, depth, thickness and description of any questionable materials.
5. Description of abutment materials including depth and thickness of pervious layers or aquifers.

6. Location, attitude, pattern and/or other pertinent data on any geologic structural features such as joints, bedding planes, faults or schistosity.
7. Location of water table and estimated rate of recharge (high, medium, low).
8. Permeability of abutments

B. Centerline of Outlet Structure

1. Location and type of test holes and number of samples collected by type.
2. Depth, thickness and description of pervious or low volume-weight strata encountered.
3. Depth and description of firm foundation materials
4. Location, depth, thickness and description of any questionable materials.
5. Location, attitude, pattern and/or other pertinent data on any geologic structural features such as joints, bedding planes, faults or schistosity.
6. Location of water table and estimated rate of recharge (high, medium, low).

C. Emergency or Other Open Spillway

1. Location and types of test holes and number of samples located by type.
2. Location, depth, thickness and description of materials encountered including:
  - a. Hard rock and/or unconsolidated material to be removed with estimated volume of each.
  - b. Material at base of excavation
  - c. Any questionable material

D. The Borrow Area(s)

1. Location of test holes and number and type of samples collected.
2. Location, depth, thickness, description and estimated quantities of various types of material encountered.

#### E. Relief Well and Foundation Drain Explorations

1. Location of test holes and number and type of samples collected.
2. Description of materials encountered including:
  - a. Location, depth, thickness and description of pervious strata.

#### F. Other Explorations

1. Purpose
2. Location of test holes and number and types of samples collected.
3. Description of materials encountered

#### G. Water Supply

1. Sources available (farm ponds, rivers, wells, municipal, etc.) and quantity.
2. Quality of water available. If questionable, what samples were taken for analysis.

#### H. Construction Materials (other than earth fill)

1. Sources of materials for concrete aggregate, riprap, impervious blanket, wells and drains.
2. Description, location and estimated quantities of materials available.

### III. Plan and Profiles

- A. Attach completed copies of Forms SCS-35A, 35B and 35C.

### IV. Interpretations, Conclusions, and Suggestions

#### A. Interpretations

1. Interpretations of the geologic conditions existing at the site.
2. Possible relation of conditions to design, construction and operation of structure.

#### B. Conclusions

1. Geologic conditions which require special considerations in design and construction.

### C. Suggestions

1. Suggestions for making most efficient use of available materials and of geologic features of the site.

#### Report Supplement for In-Service Use Only.

The geologic report should contain only basic data and facts. This report is made available for inspection upon request by non-Service interests. The report presenting interpretations, conclusions and suggestions is to be a separate report and to be labeled for in-Service use only to restrict its use to authorized Service personnel.

From the surface geology and the facts revealed by underground exploration the geologist should interpret the geologic conditions that exist at the site and the possible relation of these conditions to the suitability of the site and to the design, construction and operation of the proposed structure. Specifically he should point out any problems likely to result from the geological conditions such as: foundation weakness, seepage problems, excess ground water during construction, difficulties of excavation, spillway problems, or problems connected with available borrow materials.

The geologist should make recommendations as to various possible means and methods of overcoming problems that result from the geologic conditions. He should indicate the most efficient use of available materials and of the geologic features of the site. His recommendations might include suggestions to the design engineer on such items as location of the principal spillway, location of the emergency spillway and depth of core trench and depth of keyways into abutments. He should indicate the need for an impervious blanket, grouting or other control of excessive water loss. He should point out special problems that may be encountered during construction of the dam such as problems of excavation and the suitability of excavated rock for use as riprap, sources of concrete aggregate, and recommendations as to sources of water for construction.

#### Standard SCS Reporting Forms.

To facilitate preparation of geologic reports, standard forms have been developed which may be used in lieu of a narrative report. These are illustrated in Figures 9-5 and 9-6.

UNITED STATES DEPARTMENT OF AGRICULTURE  
SOIL CONSERVATION SERVICE

## DETAILED GEOLOGIC INVESTIGATION OF DAM SITES

General

State \_\_\_\_\_ Location \_\_\_\_\_

Watershed \_\_\_\_\_ Subwatershed \_\_\_\_\_ Fund class \_\_\_\_\_  
(FP-2; WP-1; etc.)

Site number \_\_\_\_\_ Site group \_\_\_\_\_ Hazard class \_\_\_\_\_

Investigated by \_\_\_\_\_ Date \_\_\_\_\_  
(Signature and Title)Equipment used \_\_\_\_\_  
(Type, size, make, model, etc.)Site Data

Drainage area size; Square miles \_\_\_\_\_ Acres \_\_\_\_\_

Type of structure \_\_\_\_\_ Purpose \_\_\_\_\_

Height of fill \_\_\_\_\_ feet; Length of fill \_\_\_\_\_ feet

Estimated volume of compacted fill required \_\_\_\_\_ cubic yards

Storage Allocation

	Volume (acre-feet)	Surface Area (acres)	Depth at Dam (feet)
Sediment	_____	_____	_____
Floodwater	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Surface Geology and Physiography

Physiographic area \_\_\_\_\_ Topography \_\_\_\_\_

Steepness of abutments: Left \_\_\_\_\_ percent; Right \_\_\_\_\_ percent

Width of floodplain along centerline of dam \_\_\_\_\_ feet

Geologic formations and surficial deposits \_\_\_\_\_

Attitude of beds: dip \_\_\_\_\_ strike \_\_\_\_\_

Briefly describe folding, faults, springs, caverns, slide areas, and other geologic factors which might affect the site. Use reverse side if necessary.

Sheet 1 of \_\_\_\_\_

Figure 9-5 Detailed Geologic Investigation of Dam Sites

## DETAILED GEOLOGIC INVESTIGATION OF DAM SITES (Cont'd.)

## Feature \_\_\_\_\_

(Centerline of Dam, Principal Spillway, Emergency Spillway, the Stream Channel, Investigations for Drainage of Structures, Borrow Area, Reservoir Basin, etc.)

<u>Equipment used</u>	<u>Number of holes</u>	<u>Number of Samples Taken</u>		
		<u>Undisturbed</u>	<u>Disturbed</u>	
			<u>Large</u>	<u>Small</u>
1. _____	_____	_____	_____	_____
2. _____	_____	_____	_____	_____
3. _____	_____	_____	_____	_____
4. _____	_____	_____	_____	_____
5. _____	_____	_____	_____	_____
Total	_____	_____	_____	_____

Discuss the following subjects as appropriate. Assign the item number of each subject to the paragraph discussing that subject, e.g., discussions of the volumes of common and rock excavation will be prefixed by the number "5". Use additional sheets as necessary.

## Item No.

1. Depth, thickness and description of questionable strata.
2. Depth to, and description of firm foundation.
3. Depth and description of aquifers or potential aquifers.
4. Description of geologic structural features.
5. Volumes of common and rock excavation.
6. Character of material underlying borrow area or serving as bottom of open spillways or reservoir area.
7. Other pertinent data, such as water-supply, construction material (other than earth fill), etc.

INTERPRETATIONS, CONCLUSIONS AND SUGGESTIONS  
FROM DETAILED GEOLOGIC INVESTIGATION OF DAM SITES  
(For In-Service Use Only)

State\_\_\_\_\_Location\_\_\_\_\_

Watershed\_\_\_\_\_Subwatershed\_\_\_\_\_

Site number\_\_\_\_\_Site group\_\_\_\_\_Hazard class\_\_\_\_\_

Type of structure\_\_\_\_\_Purpose\_\_\_\_\_

Height of fill\_\_\_\_\_feet; Volume of compacted fill\_\_\_\_\_cubic yards

Investigated by\_\_\_\_\_Date\_\_\_\_\_  
(Signature and Title)

Describe general geology of the site with emphasis on geologic conditions which may require special considerations in design and construction. Include suggestions which might be considered in design and construction to solve specific geologic problems. Attach additional sheets as necessary.

Sheet\_\_\_\_\_of\_\_\_\_\_

Figure 9-6 Interpretations, Conclusions and Suggestions  
from Detailed Geologic Investigation of Dam Sites



## CHAPTER 10. SAFETY

All safety practices and procedures currently established by safety handbooks and guides of the Service must be adhered to in field operations.

Emphasis on safety measures as regards drill crews should be placed on the use of safety helmets and other protective devices such as gloves and hard-toed shoes. Personnel operating drill rigs or other persons whose duties require close proximity to machinery in operation or transit, should rid themselves of ragged or torn clothing. Machinery in operation should be equipped with guards to be installed on any moving machinery parts insofar as practicable.

Equipment operators should not run the equipment in excess of the limits of capability and safety as established and designated by the manufacturer.

Equipment should not be presumed to be in safe operating condition unless it has been adequately checked by a competent, responsible person.

Regular condition checks should be made on all equipment and the results reported.

Drill crews must avoid operating equipment in the vicinity of power transmission lines.

Crews using geophysical instruments involving explosive charges should be well acquainted with the precautions necessary to avoid accidents. Only properly licensed blasters may handle, load and fire explosive charges. Until such time as this method of exploration is approved for full Service use, and Service regulations issued, it is recommended that locally employed, licensed blasters be used.

Where trench or pit excavations require side supports of cribbing, determine that the material for the cribbing is of adequate strength and is so installed that slumping, caving and sliding cannot occur.

Test holes should be covered each evening and plugged level with the surface upon completion of exploration, to prevent accidents. An open hole is a potential danger to humans and livestock, it could cause a broken leg or even more serious accidents. Test pits and trenches should also be leveled before completion of site investigations.

Avoid personal accidents! Be sure to make reports on accidents (See Administrative Procedures Handbook). Get medical assistance if required, even if it is necessary to shut down operations.

All crews should have copies of the First Aid Guide and should have first aid kits as prescribed in the Guide. Snake-bit kits are required in poisonous snake-infested areas.

Extreme caution should be exercised when moving-drilling equipment on roads, streets and highways.



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